INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1889.

28077

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1889.

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Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866. (*Deceased* 1887.)

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

The Right Hon. Lord Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

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1889.

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Institution of Mechanical Engineers, 19 *Victoria Street*, *Westminster*, *S.W.*

[Telegraphic address :—*Mech, London.*]

Institution of Mechanical Engineers.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1889.

HONORARY LIFE MEMBERS.

1883. Abel, Sir Frederick Augustus, C.B., D.C.L., D.Sc., F.R.S., 1 Adam Street, London, W.C.; and 40 Cadogan Place, London, S.W.
1878. Crawford and Balcarres, The Right Hon. the Earl of, F.R.S., 2 Cavendish Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.
1889. Eiffel, Gustave, 37 Rue Pasquier, Paris.
1888. Haughton, Rev. Samuel, M.D., D.C.L., LL.D., F.R.S., Trinity College, Dublin.
1883. Kennedy, Professor Alexander Blackie William, F.R.S., 3 Prince's Street, Westminster, S.W.
1878. Rayleigh, The Right Hon. Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.
1888. Rosse, The Right Hon. the Earl of, D.C.L., LL.D., F.R.S., Birr Castle Parsonstown.

MEMBERS.

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, 9 Disraeli Road, Upton, London, E.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester. [*Adamson, Dukinfield.*]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1886. Adamson, Thomas Alfred, 27 Leadenhall Street, London, E.C.

1878. Adcock, Francis Louis, care of I. B. Roscoe, Du Toit's pan Road, Kimberley, South Africa: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1889. Addy, George, Waverley Milling Cutter Works, Sheffield.

1887. Ahmed Bey, Colonel, Imperial Naval Arsenal, Constantinople.

1886. Aisbitt, Matthew Wheldon, 53 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.; and Savernake Lodge, Chelmsford.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; The Lindens, Kew Road, R.O., Richmond, Surrey: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, care of Mrs. W. Hudson, Middleton Hall, Pickering.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Co., Albert Works, Penistone Road, Sheffield.
1884. Allen, Alfred Evans, 37 Wellington Street, Hull.
1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.
1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.
1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works, Lambeth, London, S.E. [*Pump, London.*]
1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.
1870. Alley, John, Malahova, Bekovo Station, Moscow and Riazan Railway, Moscow, Russia: (or care of W. Cuningham, Moscow.)
1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]
1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.
1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]
1876. Allport, Charles James, Whitehall Club, Parliament Street, Westminster, S.W.
1871. Allport, Howard Aston, Dodworth Grove, Barnsley.
1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain: (or care of Messrs. G. and W. Almond, 67 Willow Walk, London, S.E.)
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.
1876. Anderson, Henry John Card, 13 Mount Ararat Road, Richmond, Surrey.
1884. Anderson, Samuel, General Manager, Westbury Iron Works, Westbury, Wiltshire.
1856. Anderson, William, D.C.L., Director-General of Ordnance Factories, Royal Arsenal, Woolwich; and Lesney House, Erith, S. O., Kent.
1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.
1867. Appleby, Charles James, Messrs. Appleby Brothers, 22 Walbrook, London, E.C. [*Millwright, London*]; and East Greenwich Works, London, S.E.
1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)
1881. Archbold, Joseph Gibson, Messrs. Ernest Scott and Co., Close Works, Newcastle-on-Tyne.
1889. Archer, Charles Frederick, Messrs. Joseph Richmond and Co., 30 Kirby Street, Hatton Garden, London, E.C.

1874. Archer, David, Oldbury Railway-Carriage and Wagon Co., Oldbury, near Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. John Birch and Co., 11 Queen Street Place, London, E.C.; and 13 Clifton Road, Brockley, London, S.E.

1887. Armit, Thomas Napier, Dundee Salvage Co., 23 Panmure Street, Dundee. [*Armit, Dundee.*]

1859. Armitage, William James, Farnley Iron Works, Leeds.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, F.R.S.E., Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, The Right Hon. Lord, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow. [*Germiston, Glasgow.* 1080.]

1887. Arrol, William, Dalmarnock Iron Works, Glasgow.

1887. Arteaga, Alberto de, 331½ Buen Orden, Buenos Aires, Argentine Republic: (or care of M. Raggio-Carneiro, 129A Winchester House, Old Broad Street, London, E.C.)

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and Ash Grove, Victoria Park, Longsight, Manchester. [*Thomas Ashbury, Manchester.*]

1888. Ashby, George, Tardeo, Bombay, India.

1884. Ashwell, Frank, Victoria Foundry, Sycamore Lane, Leicester. [*Iron, Leicester.* 100.]

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Horwich, near Bolton; and Fern Bank, Heaton, Bolton.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1889. Atkinson, Alexander, Engineer to H.H. the Maharajah of Kashmir, Kashmir, viâ Murree, Punjaub, India.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield. [*Marriott's, Sheffield.* 174.]
1875. Atkinson, Edward (*Life Member*), The Projectile Company, New Road, Wandsworth Road, London, S.W.
1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.
1885. Bailey, William Henry, Albion Works, Salford, Manchester. [*Beacon, Salford.*]
1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.
1887. Baillie, Robert Alexander, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.
1872. Bailly, Philimond, 271 Rue Rogier, Bruxelles, Belgium.
1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China; 22 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollokshields, Glasgow. [*Glacis, Glasgow.*]
1873. Baird, George, St. Petersburg; and Fulmer, Slough.
1887. Baker, William James, 2 New Street, Huddersfield. [*Patent, Huddersfield.*]
1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.
1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.
1884. Balmokand, Lala, Executive Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.
1887. Bamlett, Adam Carlisle, Agricultural Engineering Works, Thirsk.
1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.
1888. Baraclough, William Henry, Great Western Buildings, 6 Livery Street, Birmingham.
1885. Barker, Tom Birkett, Scholefield Street, Birmingham.
1882. Barlow, Henry Bernoulli, 4 Mansfield Chambers, 17 St. Ann's Square, Manchester. [*Monopoly, Manchester.*]
1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.
1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.
1881. Barnett, John Davis, Mechanical Superintendent, Grand Trunk Railway, Stratford, Ontario, Canada.
1887. Barningham, James, 27 Corporation Street, Manchester.
1884. Barr, Archibald, Professor of Engineering, The University, Glasgow.
1878. Barr, James, care of William McConnell, Underwood House, Paisley.

1883. Barras, Harry Haywood, Locomotive Superintendent, Southern Brazilian Rio Grande do Sul Railway, Rio Grande do Sul, Brazil; Broom Lodge, Rotherham: (or care of George Thomas Barras, 7 Howard Street, Rotherham.)

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Rochdale Road Station, Manchester.

1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.

1885. Barrie, William, Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., Yokohama, Japan.

1887. Barringer, Herbert, Assistant Superintendent Engineer, Messrs. Scrutton Sons and Co., 9 Gracechurch Street, London, E.C.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury. [*Barrows, Banbury.*]

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Standard Building, Montreal, Canada.

1887. Bate, Capt. Charles McGuire, R.E., War Office, Whitehall, London, S.W.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1889. Bayford, William James, Engineer, Messrs. Meakin and Co, Brewers, Delhi, India.

1872. Bayliss, Thomas Richard, Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1887. Beardmore, William, Parkhead Forge and Steel Works, Glasgow.

1880. Beaumont, William Worby, 163 Strand, London, W.C.; and Melford, Palace Road, Tulse Hill, London, S.W.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1887. Beckwith, George, Engineer, Strand and North Docks Engineering Works, Swansea; and Fairfield House, Mount Pleasant, Swansea.

1875. Beckwith, John Henry, Manager, Messrs. Galloways, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1884. Beetlestone, George John, Sudbrook Works, near Chepstow.

1888. Beldam, Asplan, 77 Gracechurch Street, London, E.C.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough.
1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; and Reform Club, Pall Mall, London, S.W. [*Sir Lowthian Bell, Middlesbrough.*]
1880. Bell, William Henry, Vale Rectory, Guernsey.
1879. Bellamy, Charles James, 5 Priory Gardens, Bedford Park, London, W.
1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]
1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.
1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]
1887. Bennetts, Edward John, 1 Dean Villas, Trevu Road, Camborne.
1878. Berrier-Fontaine, Marc, Ingénieur de la Marine, Toulon Dockyard, Toulon, France: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.) [*Berrier, Toulon.*]
1887. Bertram, William, Messrs. George and William Bertram, St. Katherine's Works, Sciennes, Edinburgh.
1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.
1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.
1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.
1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.
1883. Bicknell, Edward, care of Bank of Bengal, Calcutta, India: (or 8 Canynge Square, Clifton, Bristol).
1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.
1888. Billinton, Robert John, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.
1887. Binnie, Alexander Richardson, Town Hall, Bradford.
1877. Birch, Robert William Peregrine, 5 Queen Anne's Gate, Westminster, S.W.
1847. Birley, Henry, 6 Brentwood, Pendleton, R.O., Manchester.
1888. Birtwistle, Richard, Messrs. S. S. Stott and Co., Laneside Foundry, Haslingden, Manchester.
1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]
1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.
1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Bleehynden, Alfred, Naval Construction and Armaments Works, Barrow-in-Furness.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, Catherine Chambers, 8 Catherine Street, Strand, London, W.C.

1881. Bocquet, William, North Western Railway, Lahore, India.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1888. Borrows, William, Messrs. Edward Borrows and Sons, Providence Foundry, Sutton, St. Helen's, Lancashire.

1885. Boughton, Henry Francis, Dan Rylands, Glass Works, Barnsley; and Hunningley, near Barnsley.

1886. Boult, Alfred Julius, Messrs. W. P. Thompson and Boult, 323 High Holborn, London, W.C.

1888. Boultbee, Frederic Richard, 4 Loris Road, Shepherd's Bush, London, W.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. Bowen, Edward, Mechanical Engineer and Manager of Workshops, Porto Alegre and New Hamburg Railway, Rio Grande do Sol, Brazil: (or care of Benjamin Packham, 122 Upper Lewes Road, Brighton.)

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes (*Life Member*), Neston, near Chester.

1884. Boyer, Robert Skeffington, 8 Mount Stuart Square, Cardiff.

1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.

1889. Bradley, Isaac, Manager, Gatling Gun Works, Perry Barr, Birmingham.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich; and Norfolk House, Handsworth, R. O., Birmingham. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, Bart., D.C.L., F.R.S., 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1888. Bratt, Augustus Hicks Henery, Mechanical Engineer, New Prye River Dock, Province Wellesley, Straits Settlements: (or Sunnyside, Old Trafford, Manchester.)

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's.

1889. Brebner, Samuel Gordon, Chief Mechanical Engineer, Small Arms Ammunition Factory, Poona, India.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham. [*Breeden, Birmingham.*]

1883. Bricknell, Augustus Lea, 56 Arlington Road, Brixton, London, S.W.

1887. Brier, Henry, Scotch and Irish Oxygen Co., Rosehill Works, Polmadie, Glasgow.

1889. Briggs, Charles, Jun., Superintendent of Machinery, Companhia do Beberibe, Pernambuco, Brazil: (or care of Robert Briggs, Howden.)

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1889. Bright, Philip, Messrs. J. Tylor and Sons, 2 Newgate Street, London, E.C.

1886. Bright, William, Manager, Fairwood Tin-Plate Works, Gowerton, R.S.O., Glamorganshire.

1865. Brock, Walter, Messrs. Denny and Brothers, Engine Works, Dumbarton.

1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1884. Brook-Fox, Frederick George, Executive Engineer, South Indian Railway, Cuddalore, Madras Presidency, India: (or care of Messrs. H. S. King and Co., 65 Cornhill, London, E.C.)

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W. [*Brotherhood, London.*]

1886. Brown, Andrew, Messrs. T. Cosser and Co., McLeod Road Iron Works, Kurrachee, India: (or care of P. B. Brown, Hecla Works, Sheffield.)

1866. Brown, Andrew Betts, F.R.S.E., Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1879. Brown, Charles, Messrs. Charles Brown and Co., 91 Rione Amedeo, Naples, Italy: [*Brown Comp., Naples.*] (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Superintendent Dominion Bridge Co., Lachine Locks, P.Q., Canada.

1889. Brown, Frederick Alexander William, Royal Laboratory, Royal Arsenal, Woolwich.

1888. Brown, Frederick Gills, Messrs. Brown and David, Australian Chambers, Queen Street, Brisbane, Queensland; and care of Commissioner, Australian Irrigation Colonies, 35 Queen Victoria Street, London, E.C.

1881. Brown, George William, Messrs. Huntley Boorne and Stevens, Reading Tin Works, Reading.

1863. Brown, Henry, 13 Summer Row, Birmingham.

1887. Brown, James, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne.

1884. Brown, Oswald, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Acqua, London.*]

1888. Brown, William, Messrs. W. Simons and Co., London Works, Renfrew.

1887. Browne, Frederick John, Tay Creggan, Ealing Dean, London, W.

1874. Browne, Tomyns Reginald, District Locomotive Superintendent, East Indian Railway, Asansol, Bengal, India; care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.

1874. Bruce, Sir George Barclay, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W.

1889. Bruce, Robert, Ethelburga House, 70 and 71 Bishopsgate Street Within, London, E.C.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 23 Rowland Gardens, South Kensington, London, S.W.

1888. Bruff, Charles Clarke, Coalport China Co., Coalport, near Ironbridge, Salop.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W. [3024.]

1870. Brunlees, Sir James, F.R.S.E., 12 Victoria Street, Westminster, S.W.

1887. Brunton, Philip George, Resident Engineer, Department of Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of J. D. Brunton, 19 Great George Street, Westminster, S.W.)

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

1888. Bryce-Douglas, Archibald Douglas. Naval Construction and Armaments Works, Barrow-in-Furness.

1873. Buckley, Robert Burton, Executive Engineer, with Supreme Government of India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1887. Buckton, Walter, 27 Ladbroke Square, London, W.

1878. Buddicom, Harry William, Plas-Derwen, Abergavenny.
1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester. [*Manometer, Manchester.* 899.]
1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes and Co., 90 Cannon Street, London, E.C.)
1881. Bulkley, Henry Wheeler, 149 Broadway, New York.
1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.
1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.
1884. Bunning, Charles Ziethen, 66 Bishopgate Street, Norwich.
1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)
1884. Bunting, George Albert, National Liberal Club, Whitehall Place, London, S.W.
1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.
1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.
1878. Burnett, Robert Harvey, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]
1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]
1887. Burstal, Edward Kynaston, Engineer to the Corporation of Oxford, Corporation Water Works, Oxford.
1877. Burton, Clerke, 22 Oakfield Street, Roath, Cardiff.
1884. Butcher, Joseph John, Edge Moor Iron Works, Post Office, Wilmington, Delaware, United States.
1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]
1888. Butter, Frederick Henry, Carriage Department, Royal Arsenal, Woolwich; and 4 Hanover Road, Brookhill Park, Plumstead.

1887. Caiger, Emery John, Messrs. W. J. Helmore and Co., 51 Lime Street, London, E.C.
1889. Callan, William, River Plate Fresh Meat Co., 2 Coleman Street, London, E.C.
1886. Cambridge, Henry, Stuart Chambers, Mount Stuart Square, Cardiff.
1877. Campbell, Angus, Logie, Mussoorie, N. W. Provinces, India.
1880. Campbell, Daniel, Messrs. Campbell and Schultz, 90 Cannon Street, London, E.C. [*Duke, London.* 1893.]
1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineco, Leeds.*]

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java: (or care of R. Campbell, Slamat Cottage, Mount Vernon, Glasgow.)

1885. Capito, Charles Alfred Adolph, 12 Prince's Street, Hanover Square, London, W.; and 9 Belgrave Terrace, Lee, London, S.E.

1860. Carbutt, Edward Hamer, 19 Hyde Park Gardens, London, W.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Indian State Railway Establishment; care of Messrs. King King and Co., Bombay, India: (or care of Rev. J. H. Cardew, Wingfield Rectory, Trowbridge.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1887. Carlyle, Thomas, Inspector of Ordnance Machinery, Royal Artillery, Singapore: (or 72 Glyndon Road, Plumstead.)

1869. Carpmael, Frederick, 106 Croxted Road, West Dulwich, London, S.E.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, Chief Engineer, London and India Docks Joint Committee, Dock House, 109 Leadenhall Street, London, E.C.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Holly House, Gateshead. [*Wardale, Gateshead.*]

1888. Carrick, Samuel Stewart, Superintendent Engineer, Shaw Savill and Albion Steamship Co., 34 Leadenhall Street, London, E.C.

1874. Carrington, William T. H., 72 Mark Lane, London, E.C.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1885. Carter, Herbert Fuller, La Compañia Unida, Guanajuato, Mexico: (or care of H. M. Carter, 1 Gresham Buildings, Basinghall Street, London, E.C.)

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1888. Castle, Frank, Normal School of Science, South Kensington, London, S.W.

1883. Cawley, George, 358 Strand, London, W.C.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1886. Chalmers, John Reid, 52 Amwell Street, Claremont Square, London, E.C.

1884. Chamberlain, John, Metropolitan Gas Works, West Melbourne, Melbourne, Victoria: (or care of J. Chamberlain, 188 West Ferry Road, Millwall, Poplar, London, E.)

1887. Chapman, Alfred Crawhall, 2 St. Nicholas' Buildings, Newcastle-on-Tyne.

1888. Chapman, Arthur, Messrs. Marillier and Edwards, 1 Hastings Street, Calcutta, India.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 69 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1885. Chapman, John, Engineer, Windsor and Eton Water Works, Eton.

1887. Chapman, Joseph Crawhall, 70 Chancery Lane, London, W.C.

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1887. Chatwin, James, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham. [*Chatwin, Birmingham.*]

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and Irwell House, Drinkwater Park, Prestwich, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, The Terrace, H.M. Dockyard, Sheerness.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1886. Chittenden, Edmund Barrow, Messrs. Chittenden Knight and Co., Sittingbourne; and Manor House, Offham, West Malling, near Maidstone.

1857. Chrimes, Richard, Moorgate Grange, Rotherham.

1888. Chubb, Thomas Lyon, Ferro Carril del Sud, Buenos Aires, Argentine Republic.

1880. Churchward, George Dundas, Locomotive Superintendent, China Railway Company, care of H.B.M.'s Consulate, Tientsin, North China: (or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough.)

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1889. Clark, Thomas Alexander, Superintendent of Workshops, George Heriot's Hospital School, Edinburgh.

1889. Clarke, Francis, Dane John Iron Works, Canterbury.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln. [*Claytons, Lincoln.*]

1886. Clayton, Samuel, St. Thomas' Engine Works, Sunbridge Road, Bradford.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1871. Cleminson, James, Dashwood House, 9 New Broad Street, London, E.C. [*Catamarca, London.*]

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln. [*Robey, Lincoln.*]

1885. Clifton, George Bellamy, Great Western Railway Electric Light Works, 150 Westbourne Terrace, Paddington, London, W.

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, 52 High Street, Redcar.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1887. Cochrane, George, Resident Engineer, London Hydraulic Power Works, 46 Holland Street, Blackfriars Road, London, S.E.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1889. Coey, Robert, Assistant Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1889. Colam, William Newby, Engineer, Cable Tramways, Henderson Row, Edinburgh.

1884. Cole, Charles, Messrs. Cole Booth and Co., Vulcan Works, Dudley Hill, Bradford.

1878. Cole, John William, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.

1884. Collenette, Ralph, 38 Dixon Street, Rotherham.

1888. Colley, Benjamin, Laburnum Villa, Westbromwich.

1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Stee Works, Tredegar.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1888. Combe, Abram, Messrs. Combe Barbour and Combe, Falls Foundry, Belfast.

1889. Common, John Freeland Fergus, 4 Bute Crescent, Cardiff.

1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1888. Constantine, Ezekiel Grayson, 5A New Brown Street, Manchester.

1874. Conyers, William, Engineer, New Zealand Pine Works, Invercargill, New Zealand.

1888. Cook, John Joseph, Messrs. Robinson Cooks and Co., Atlas Foundry, St. Helen's, Lancashire.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]

1877. Cooper, George, Pencliffe, Alleyne Road, West Dulwich, London, S.E.

1874. Cooper, William, Neptune Engine Works, Hull. [*Neptune, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness. [*Engine, Barrow-in-Furness.*]

1885. Coppée, Evenee, 223 Avenue Louise, Bruxelles, Belgium.

1884. Corder, George Alexander, 74 Ivydale Road, Nunhead, London, S.E.

1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath, [*Stothert, Cornes, Bath.*]; and 76 Cannon Street, London, E.C. [*Stothert, Cornes, London.*]

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1884. Cotton, John, Messrs. E. Ripley and Sons, Bowling Dye Works, Bradford.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton. [*Beehive, Bolton.*]

1887. Coulman, John, Hull and Barnsley Railway, Spring Head Works, Hull.

1868. Coulson, William, 1 Pimlico, Durham.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.; and 76 Redcliffe Square, South Kensington, London, S.W.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1887. Crabbe, Alexander, Champdany Jute Works, Serampore, Bengal.

1883. Crampton, George, 14 Victoria Street, Westminster, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1889. Cribb, Frederick James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1884. Crighton, John, Union Engineering Co., 2 Clarence Buildings, Booth Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1883. Croft, Henry, Chemanns, Vancouver Island.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, London, S.E.

1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]

1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.

1881. Crosland, James Foyell Lovelock, Chief Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Eirianfa, Llangollen.

1871. Crossley, William, 153 Queen Street, Glasgow. [*Crossley, Glasgow.* 584.]

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]
1888. Crowe, George, Albion Chambers, Bute Docks, Cardiff.
1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.
1886. Cryer, Thomas, Mechanical Engineering Department, Manchester Technical School, Princess Street, Manchester; and Urmston, near Manchester.
1889. Cullen, William Hart, Resident Engineer, The Aluminium Co., Oldbury, near Birmingham.
1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester. [*Curtius, Manchester.*]
1887. Cutler, George Benjamin, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E.; and 4 Westcombe Park, Blackheath, London, S.E.
1876. Cutler, Samuel, Messrs. Samuel Cutler and Sons, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]

1888. Dadabhoy, Cursetjee, Messrs. Shapurji Sorabji and Co., Bombay Foundry and Engine Works, Khetwady, Bombay, India.
1864. Daglish, George Heaton, Rock Mount, St. Anne's Road, Aigburth, near Liverpool. [*Daglish, Aigburth.* 2717.]
1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris; and 16 Rue des Chesneaux, Montmorency, Seine-et-Oise, France.
1886. Dale, Thomas, Townsend Foundry, Kirkcaldy.
1889. Dalgarno, James Robert, Danesford, Countess Wells Road, Mannofield, Aberdeen.
1881. D'Alton, Patrick Walter, London Electric Supply Corporation, Stowage Wharf, Deptford, London, S.E.
1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.
1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Fern Bank, Horsforth, Leeds.
1888. Darbishire, James Edward, 110 Cannon Street, London, E.C.
1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.
1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds [*Sun Foundry, Leeds*]; and 3 Prince's Street, Westminster, S.W.
1865. Davidson, James, Crescent Villa, Lower Eglinton Road, Plumstead.

1884. Davidson, James Young, 13 Fairlawn Avenue, Acton Green, Chiswick, London, W.

1888. Davidson, Samuel Cleland, Sirocco Works, Bridge End, Belfast.

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1880. Davies, Charles Merson, Locomotive Carriage and Wagon Superintendent, Bengal-Nagpur Railway, Nagpur, Central Provinces, India.

1885. Davies, Edward John Mines, 165 Tachbrook Street, South Belgravia, London, S.W.

1874. Davis, Alfred, 2 St. Ermin's Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 53 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 90 Cannon Street, London, E.C.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1877. Davison, John Walter, care of W. G. P. Joyner, Pirie Chambers, Pirie Street, Adelaide, South Australia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield. [*Motor, Sheffield.*]

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Staffa Lodge, South Park Hill Road, Croydon.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1869. Day, St. John Vincent, F.R.S.E., Cawder House, Bishopbriggs, near Glasgow.

1886. Dayson, William Ogden, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool.

1880. Deacon, Richard William, Messrs. Samuel Fisher and Co., Nile Foundry, Birmingham; and 19 Clarendon Road, Edgbaston, Birmingham.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1887. Deas, James, Clyde Navigation, Glasgow.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France. [*Decauville, Corbeil.*]

1877. Dees, James Gibson, 36 King Street, Whitehaven.
1889. Defries, Wolf, Messrs. Defries and Sons, 147 Houndsditch, London, E.; and 4 Cleveland Gardens, Bayswater, London, W.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1882. Denison, Samuel, Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]
1883. Dennis, William Frederick, 101 Leadenhall Street, London, E.C. [*Fredennis, London.* 559.]
1888. Dent, Charles Hastings, Locomotive Department, London and North Western Railway, Preston.
1883. Dick, Frank Wesley, Newton Steel Works, near Glasgow.
1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]
1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.
1888. Dickson, George Manners, Assistant Engineer, Calcutta Water Works, Municipal Office, Calcutta, India.
1886. Dixon, Robert, Messrs. Dixon and Corbitt, Teams Hemp and Wire Rope Works, Gateshead. [*Dixon, Gateshead.*]
1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester. [*Tools, Manchester.*]
1887. Dixon, William Basil, Earle's Shipbuilding and Engineering Works, Hull.
1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]
1873. Dobson, Richard Joseph Caistor, Suiker Fabrick, Kalibayor, Banjoemas, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)
1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]
1889. Dolby, Ernest Richard, Abbey Buildings, Prince's Street, Westminster, S.W.
1889. Donald, James, care of J. Macfarlane Gray, St. Katharine Dock House, Tower Hill, London, E.
1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.
1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.
1884. Donnelly, John, 45 Brockley Road, London, S.E.
1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, F.R.S., Trinity House, London, E.C. [2242.]; and Stella House, Dulwich, London, S.E.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1887. Douglass, William Tregarthen, Executive Engineer, Bishop Rock and Round Island Lighthouses, Scilly Islands; and Trinity House, London, E.C.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster [*Redbourn, Frodingham.*]; and Hatfield House, Hatfield, near Doncaster.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W. [*Gaseous, London.*]

1886. Doxford, Charles David, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C. [3663.]

1886. Drummond, Dugald, Locomotive Superintendent, Caledonian Railway, St. Rollox Works, Glasgow.

1889. Drummond, Richard Oliver Gardner, De Beer's Diamond Mining Co., Kimberley, South Africa.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 184 Lewisham Road, London, S.E. [*Duckham, London.*]

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Doucine, London.*]; and 10 Airlie Gardens, Campden Hill, Kensington, London, W.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Knysna, Cape Colony; and Livonia, Goldsmith Gardens, Acton, London, W.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]; and Glemham Lodge, New Barnet.
1887. Dymond, George Cecil, Messrs. W. P. Thompson and Co., 6 Lord Street, Liverpool.
1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.
1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.
1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.
1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.
1888. Eaton-Shore, George, Borough Engineer, Temple Chambers, Crewe.
1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.
1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.
1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.
1887. Edlin, Herbert William, Cradock, Cape Colony: (or The Limes, Ellerton Road, Surbiton, R. O., Kingston-on-Thames.
1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.
1871. Edwards, Edgar James, 12 Dartmouth Street, Westminster, S.W.; and 42 Rye Hill Park, Peckham, London, S.E.
1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.
1888. Ellery, Henry George, Messrs. Gent and Co., Faraday Works, Leicester.
1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.
1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses. [*Elliot Company, London.*]
1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]
1869. Elliott, Henry Worton, Selly Oak Works, near Birmingham. [*Elmeco, Birmingham.*]
1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.
1880. Ellis, Oswald William, 6 Grosvenor Place, Jesmond, Newcastle-on-Tyne. [*Robey, Newcastle-on-Tyne.*]

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India.

1875. Elwell, Thomas, 223 Avenue de Paris, Plaine St. Denis, Seine, France.

1878. Elwin, Charles, London County Council, Spring Gardens, London, S.W.

1889. Emett, George Henry Hawkins, Hope Foundry, Dewsbury. [*Emett, Dewsbury.*]

1885. Errington, William, 28 and 29 Insurance Buildings, Auckland, New Zealand. [*Refunditur, Auckland.*]

1889. Etches, Harry, Messrs. Etches Brothers, Eastbourne Engineering Works, Eastbourne.

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1887. Evans, Arthur George, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Evans, David, Barrow Hæmatite Steel Works. Barrow-in-Furness.

1888. Evans, Joseph, Culwell Foundry, Wolverhampton.

1885. Evans, Richard Kendall, Engineering Works, Sandiacre, near Nottingham; and Whiston Grange, Rotherham.

1887. Everard, John Breedon, 6 Millstone Lane. Leicester.

1887. Everitt, Nevill Henry, Patent Shaft Works, Wednesbury.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Smithfield Works, Sherlock Street, Birmingham.

1869. Faija, Henry, 2 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and Askham Richard, York.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

1882. Fawcett, Thomas Constantine, White House Engineering Works, Leeds. [*Fawcett, Leeds.*]

1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham; and The Ferns, Stapleford, near Nottingham. [*Fearfield, Nottingham.*]

1888. Featherstone, William Bromley, Engineer and Manager, Dundalk Gas Works, Dundalk.

1882. Feeny, Victor Isidore, 7 Queen Victoria Street, London, E.C. [*Victor Feeny, London.*]

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London. E.C.

1877. Fenton, James, 8 Great George Street, Westminster, S.W.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]

1870. Ferguson, Henry Tanner, Torre Mount, Torquay.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1854. Fernie, John, P. O. Box, Hutchinson, Kansas, United States.

1866. Fiddes, Walter, Clapton Villa, Belgrave Road, Tyndall's Park, Bristol.

1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1888. Field, Howard, Messrs. John Bell and Son, 118A Southwark Street, London, S.E.; and Southall.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1887. Firth, William, Water Lane, Leeds.

1888. Fischer, Gustave Joseph, Resident Engineer, Railway Department, Sydney, New South Wales.

1889. Fisher, Henry Bedwell, Locomotive Works, London Brighton and South Coast Railway, Brighton.

1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.

1888. FitzGerald, Maurice Frederick, Professor of Engineering, Queen's College, Belfast.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]

1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users, Manchester.*]

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1887. Foley, Nelson, Engineering Manager, Società Industriale Napoletana Hawthorn-Guppy, Naples, Italy.

1886. Folger, William Mayhew, Commander, United States Navy, Bureau of Ordnance, Naval Department, Washington, D.C., United States.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta.

1882. Forbes, William George London Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1888. Forster, Alfred Llewellyn, Assistant Engineer, Newcastle and Gateshead Water Works, Newcastle-on-Tyne.

1888. Forster, Edward John, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1882. Forsyth, Robert Alexander, Courtway, Gold Tops, Newport, Monmouthshire.

1889. Foster, Ernest Howard, Messrs. Henry R. Worthington, 145 Broadway, New York; and 43 Rue Lafayette, Paris.

1886. Foster, Frederick, Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N. [*Drinks, London.* 306.]

1889. Foster, Herbert Anderton, Messrs. John Foster and Son, Black Dike Spinning Mills, Queensbury, near Bradford.

1888. Foster, James, Samarang, Java; and Baltic Chambers, Sunderland. [*Java, Sunderland.*]

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1885. Fourny, Hector Foster, Earle's Shipbuilding and Engineering Works, Hull.

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1885. Fowler, William Henry, Chadderton Iron Works, Irk Vale, Chadderton, near Oldham.

1866. Fox, Sir Douglas, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1888. Francken, William Augustus, Public Works Department, India; care of Messrs. Grindlay Groom and Co., Bombay, India.

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Goldsbrough Mort and Co., 149 Leadenhall Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E. [*Pressure, London.* 5120.]

1888. Frenzel, Arthur Benjamin, 49 Warren Street, New York, United States.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1886. Fulton, Arthur Robert William, Resident Engineer, Wellington and Manawatu Railway, Wellington, New Zealand.

1884. Furness, Edward, Knollcroft, Knoll Road, Bexley, S.O., Kent.

1882. Furrell, Edward Wyburd, Bank of Commerce Building, St. Louis, Missouri, United States.

1887. Gaertner, Ernst, I. Fichtegasse 5, Vienna, Austria.

1866. Galloway, Charles John, Messrs. Galloways, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Sir Douglas, K.C.B., D.C.L., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1888. Gaze, Edward Henry James, 4 Victoria Drive, Mount Florida, Glasgow.

1888. Geddes, Christopher, Leeds Forge, Leeds.

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1887. Gibb, Andrew, Managing Engineer, Messrs. Rait and Gardiner, Millwall Docks, London, E.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1883. Gilchrist, Percy Carlyle, Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London*]; and Frognal Bank, Finchley New Road, Hampstead, London, N.W.

1856. Gilkes, Edgar, Westholme, Grange-over-Sands, viâ Carnforth, Lancashire.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1889. Gill, Frederick Henry, Messrs. Kerr Stuart and Co., 20 Bucklersbury, London, E.C.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1884. Girdlestone, John Ward, Engineer, Bristol Docks, Bristol.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1887. Gledhill, Manassah, Sir Joseph Whitworth and Co., Openshaw, Manchester.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1888. Goff, John, Messrs. Salt and Co., The Brewery, Burton-on-Trent.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland: (or care of Messrs. James McEwan and Co., 27 Lombard Street, London, E.C.)

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester. [*Goldsworthy, Manchester.*]

1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.

1884. Good, Henry, Messrs. Jardine and Co., Shanghai, China: care of Marine Engineers' Institute, Shanghai, China.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1884. Goodger, Walter William, Messrs. George Fletcher and Co., Masson and Atlas Works, Litchurch, Derby.

1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.

1889. Goold, William Tom, 39 Queen Victoria Street, London, E.C.; and Broxbourne, S.O., Herts.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of James Bird, 118 Cannon Street, London, E.C.)

1887. Gordon, Alexander, Niles Tool Works, and Messrs. Gordon and Maxwell, Hamilton, Ohio, United States.

1875. Gordon, Robert, Chief Engineer to the Government, Bangkok, Siam: (or Guilsborough, Northampton.)

1888. Gore, Arthur Saunders, Locomotive Superintendent, Listowel and Ballybunion Railway, Listowel, County Kerry, Ireland.

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1887. Gourlay, Charles Gershom, Messrs. Gourlay Brothers and Co., Dundee Foundry, Dundee.

1878. Grafton, Alexander, Vulcan Works, Bedford. [*Grafton, Bedford.*]

1865. Gray, John Macfarlane, Chief Examiner of Engineers, Marine Department, Board of Trade, St. Katharine Dock House, Tower Hill, London, E.; and 1 Claremont Road, Forest Gate, London, E. [*Yarg, London.*]

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1879. Gray, Thomas Lowe, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.; and Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, 15 Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., M.P., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1888. Green, Henry Joseph Kersting, Engineer, Bishnanth Tea Co., Charalli Post Office, Assam, Bengal.

1871. Greener, John Henry, 15 Walbrook, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Birmingham Small Arms and Metal Co., Adderley Park Works, Birmingham.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Greig, Fowler, Leeds.* 155.]

1885. Greig, David, Jun., Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1879. Grenville, Robert Neville, Butleigh Court, Glastonbury.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester. [*Brake, Manchester.*]

1883. Grew, Frederick, care of F. W. Grew, Victoria Iron Works, Sowerby Bridge.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Edwin James, Beechwood, Reigate.

1884. Griffiths, James E., Messrs. Griffiths and Wills, Merchants' Exchange, Cardiff. [*Griffwill, Cardiff.*]

1873. Griffiths, John Alfred, O'Keefe Estate, South Brisbane, Queensland.

1889. Grimshaw, James Walter, Resident Engineer, Harbours and Rivers Department, Sydney, New South Wales; and Australian Club, Sydney, New South Wales.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham. [*Cowen, Nottingham.* 87.]

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

1884. Gulland, James Ker, Diamond Drill Co., 8 Victoria Street, Westminster, S.W. [*Gulland, London.*]

1886 Guy, Charles Williams, Laurel Bank, Penge, London, S.E.

1870. Gwynne, James Eglinton Anderson (*Life Member*), Essex Street Works, Strand, London, W.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1888. Hadfield, Robert Abbott, Hecla Foundry Steel Works, Sheffield. [*Hadfield, Sheffield.*]

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 111 Federal Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Managing Director, Messrs. John Penn and Sons, Greenwich, London, S.E.

1882. Hall, John Willim, Ivy House, Bilston.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1886. Hall, William Jeremiah, Harbour Engineer, Limerick, Ireland.

1871. Hall, William Silver, Messrs. Takata and Co., Ginza San Chome 18, Banchi, Tokio, Japan; and 88 Bishopsgate Street Within, London, E.C.

1889. Hall-Brown, Ebenezer, Messrs. Thomas Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1880. Hallett, John Harry, 120 Powell's Place, Bute Docks, Cardiff. [*Consulting, Cardiff.*]

1871. Halpin, Druitt, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W. [*Halpin, London.* 3075, care of Victoria Chambers Co.]

1888. Hamilton, Alfred George, 14 Griffin Street, York Road, London, S.E.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Jundiahy, São Paulo, Brazil; (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1886. Hanbury, John James, Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1870. Hannah, Joseph Edward, Water Works, Winnipeg, Manitoba, Canada.

1888. Harada, Torazo, Superintending Engineer, Osaka Shipping Co., Osaka, Japan.

1888. Harding, Thomas Walter, Tower Works, Leeds.

1874. Harding, William Bishop, Zerge-utcza 13, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, 13 Riemergasse, Stadt, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1887. Hargraves, Richard, Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1887. Hargreaves, John Henry, Messrs. Hick Hargreaves and Co., Soho Iron Works, Crook Street, Bolton.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil: (or care of Jesse T. Curtis, Hill Street, Poole.)

1888. Harker, William, Messrs. Richard Schram and Co., 17A Great George Street, Westminster, S.W.

1888. Harland, Sir Edward James, Bart., M.P., Messrs. Harland and Wolff, Belfast; Glenarm Castle, County Antrim; and 24 Kensington Palace Gardens, London, W.

1873. Harman, Harry Jones, 36 Gaisford Street, Kentish Town, London, N.W.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

1885. Harris, John Henry, Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C. [*Tuneharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.; and Oak Hill, Surbiton, R.O., near Kingston-on-Thames.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1888. Harrison, George, Percy Street, Fartown, Huddersfield.

1885. Harrison, Joseph, Normal School of Science, South Kensington, London, S.W.

1887. Harrison, Thomas Henry, Messrs. Davey Paxman and Co., 139 Queen Victoria Street, London, E.C.; and 22 Granville Villas, Earlsfield Road, Wandsworth, London, S.W.

1883. Hart, Frederick, 36 Prospect Street, Poughkeepsie, New York, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.)

1882. Hart, Norman, London Chatham and Dover Railway, Locomotive (Marine) Department, Dover.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.

1886. Harvey, John Boyd, The Liverpool Nitrate Co., Oficina Ramirez, Iquique, Chile: (or care of Robert Harvey, 12 Kensington Gore, London, S.W.)

1883. Harvey, Robert, 12 Kensington Gore, London, S.W.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C. [*Haskins, London.* 1539.]; and Fallulah, York Road, West Norwood, London, S.E.

1881. Haslam, Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]

1858. Haswell, John A., Ravensworth Crescent, Low Fell, near Gateshead.

1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.

1888. Hattori, Shiun-ichi, Owari Cotton Mill, Atsuta, Owari, Japan.

1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.

1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]

1885. Haughton, Thomas James, 27 Piccadilly, London, W.

1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]

1879. Hayes, John, Messrs. Gwynne and Co., Essex Street Works, Strand, London, W.C.; and 28 Connaught Road, Harlesden, London, N.W.

1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.

1888. Head, Harold Ellershaw, Messrs. Conway Brothers, Pontrhydyrun Works, near Newport, Monmouthshire.

1869. Head, Jeremiah, Queen's Square, Middlesbrough, [*Head, Middlesbrough.*]; and 26 Lombard Street, London, E.C.

1873. Headly, Lawrance, Exchange Iron Foundry and Implement Works, Corn Exchange Street, Cambridge; and 1 Camden Place, Cambridge. [*Vanes, Cambridge.*]

1857. Healey, Edward Charles, 163 Strand, London, W.C.

1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]

1889. Heath, George Wilson, Messrs. Heath and Co., Observatory Works, Crayford, Kent.

1888. Heatly, Harry, care of Messrs. S. K. Daw and Co, 29 Clive Street, Calcutta, India.

1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester. [*Spherical, Newton Heath.*]

1879. Henchman, Humphrey, English Scottish and Australian Chartered Bank, Sydney, New South Wales: (or care of John Henchman, Uplands, Wallington, Surrey.)

1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1883. Henderson, William, Engineer, South East Mysore Gold Mine, near Colar Road, Mysore, India.

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; and 3 Beckett Terrace, Uxbridge.

1888. Henning, Gustavus Charles, 18 Cedar Street, New York, United States.

1879. Henriques, Cecil Quixam, 113 Cannon Street, London, E.C.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1884. Hernu, Arthur Henry, 69 Victoria Street, Westminster, S.W.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1887. Hibbert, George, Hibbert's Works, Bank Road, Gateshead-on-Tyne.

1871. Hick, John, Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, care of Don Juan Llona, Casilla 350, Santiago, Chili: (or care of John Hicken, Bourton, near Rugby.)

1864. Hide, Thomas C., 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, R.S.O., Yorkshire.

1889. Hill, Arthur Ripley, Messrs. Hill Brothers, Nevins Foundry, Hunslet, Leeds.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.

1873. Hilton, Franklin, Chief Engineer, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough: and South Bank, R.S.O., Yorkshire.

1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham [*Hind, Nottingham.*]; and 62 Blackfriars Road, London, S.E.

1885. Hindmarsh, Thomas, 303 King Street West, Hammersmith, London, W.

1887. Hindson, William, Messrs. J. Abbot and Co., Park Works, Gateshead.

1870. Hodges, Petronius, 142 Burngreave Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1889. Hodgson, George Herbert, Thornton Road, Bradford.

1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.

1884. Hogg, William Thomas, Ram Brewery, Wandsworth, London, S.W.

1889. Hoggins, Alfred Farquharson, Messrs. Fowler Lancaster & Co., Albert Works, Graham Street, Birmingham.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.

1884. Holland, Calvert Bernard, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1886. Hollis, Charles William, Messrs. Ketton and Hollis, Meadow Tool Works, Mayfield Grove, Nottingham.

1885. Hollis, Henry William, North Lodge, Darlington.

1883. Holroyd, John, Tomlinson Street, Hulme, Manchester. [*Knit, Manchester.*]

1885. Holroyd, John Herbert, West's Patent Press Company, Etawah, N.W. Provinces, India.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, The Cedars, Didsbury, Manchester.

1867. Holt, William Lyster, 17 Parliament Street, Westminster, S.W.

1888. Homan, Harold, Messrs. Homan and Rodgers, Dawson Street, Manchester.

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.

1856. Hopkinson, John, Inglewood, St. Margaret's Road, Bowdon, near Altrincham.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham; and 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W. [3092.]

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1889. Hopwood, John, Locomotive Superintendent, Argentine Great Western Railway, Mendoza, Argentine Republic.

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]

1889. Horsfield, Cooper, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.
1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.
1871. Horton, George, 4 Cedars Road, Clapham Common, London, S.W.
1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.
1889. Hosken, Richard, Severn Tunnel Works, Sudbrook, near Chepstow.
1873. Hoskin, Richard, 1 East Parade, Sheffield.
1888. Hosking, Thomas, Messrs. T. and J. Hosking, Dockhead Iron Works, 53 Parker's Row, Bermondsey, London, S.E.
1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.
1889. Houghton, Thomas Harry, Water Works, Crown Street, Sydney, New South Wales: (or care of Messrs. James Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.)
1887. Houghton-Brown, Ernest, Messrs. Houghton-Brown Brothers, Kingsbury Iron Works, Ballspond, London, N.
1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1860. Howard, James, Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire.
1879. Howard, James Harold, Britannia Iron Works, Bedford; and Kempston Grange, Bedford.
1882. Howard, John William, 78 Queen Victoria Street, London, E.C.
1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]
1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]
1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]
1882. Howl, Edmund, Messrs. Lee Howl and Co, Tipton. [*Howl, Tipton.*]
1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]
1884. Hoyle, Frank Edward, Locomotive Superintendent, Bahia and San Francisco Railway, Periperi, Bahia, Brazil: (or care of Leonard Micklem, Secretary, Bahia and San Francisco Railway, 38 New Broad Street, London, E.C.)
1887. Hoyle, James Rossiter, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.
1882. Hudson, John George, Glenhaven, Hayne Road, Beckenham.
1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1881. Hughes, Edward William Mackenzie, Locomotive and Carriage Superintendent, North-Western State Railway, Sukkur, Sindh Section, India; and care of Messrs. H. S. King and Co., 45 Pall Mall, London, S.W.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1889. Hughes, John, Messrs. Hughes and Lancaster, City Road, Chester.

1871. Hughes, Joseph, Kingston, Wareham.

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1880. Humphrys, James, 16 and 17 Leadenhall Buildings, London, E.C.; and Arundel House, Lancaster Road, South Norwood Park, London, S.E.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1889. Hunter, Charles Lafayette, Engineer, Bute Docks, Cardiff.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1888. Huxley, George, 20 Mount Street, Manchester.

1885. Hyland, John Frank, Engineer to Navigation of Paulista Railway, Campinas, São Paulo, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, 22 St. Ann's Square, Manchester.

1888. Ingleby, Joseph, 20 Mount Street, Manchester.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.

1883. Instone, Thomas, 22 Leadenhall Buildings, Leadenhall Street, London, E.C.

1889. Irvine, William Charles, Messrs. Irvine and Co., Harbour Dockyard, West Hartlepool.

1887. Ivatt, Henry Alfred, Locomotive Engineer, Great Southern and Western Railway, Inchicore Works, near Dublin.

1887. Ivatts, Lionel Edward, 50 Avenue de la Grande Armée, Paris.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and 72 Stafford Street, Wednesbury.

1859. Jackson, Matthew Murray, 47 Norton Road, West Brighton, Brighton; and care of Messrs. Howard and Pitcairn, 155 Fenchurch Street, London, E.C.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1873. Jackson, Samuel, C.I.E., Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1886. Jackson, Thomas, Yorkshire College, Leeds.

1889. Jackson, William, Thorn Grove, Mannofield, Aberdeen.

1872. Jackson, William Francis, Sterndale House, Litton, near Stockport.

1873. Jacob, Edward Westley, 3 Woodside Terrace, Grange Road, Darlington.

1876. Jacobs, Charles Mattathias, 88 Bishopsgate Street Within, London, E.C. [*Vexillum, London.*]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1889. James, Charles William, Continental Oxygen Co., 7 Rue Gavarni, Passy, Paris.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1889. James, Reginald William, 1 Queen Victoria Street, London, E.C.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1888. Jaques, Lieut. William Henry, Secretary to Ordnance Committee, United States; and Bethlehem Iron Works, Bethlehem, Pa., United States.

1888. Jeejeebhoy, Piroshaw Bomanjee, 17 Church Street, Bombay, India.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1863. Jeffreys, Edward Alexander, Monk Bridge Iron Works, Leeds; and Hawkhills, Chapel Allerton, Leeds. [*Gipton, Leeds.* 1614.]

1877. Jeffreys, Edward Homer, 5 Westminster Chambers, 9 Victoria Street, Westminster, S.W.

1884. Jenkins, Alfred, Sirhowy House, Romilly Road, Canton, near Cardiff.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1889. Jessop, George, London and Leicester Steam-Crane and Engine Works, Leicester.

1886. Jewell, Henry William, Messrs. Jewell and Son, City Foundry, Winchester.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 Kings Buildings, Chester.

1882. Johnson, Charles Malcolm, Inspector of Machinery, Superintending Engineer, H.M. Dockyard, Bermuda; and 11 Napier Street, Stoke, Devonport.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works. Wednesbury.

1888. Johnson, Lawrence Potter, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1887. Johnson, Samuel Henry, Engineering Works, Carpenter's Road, Stratford, London, E.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1886. Johnson, William, 3 Kirbey Street, Poplar, London, E.

1888. Johnson, William, Castleton Foundry and Engineering Works, Armley Road, Leeds.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristoi; and 2 Elmdale Road, Redland, Bristol.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Messrs. Greenwood and Batley, Albion Works, Leeds; and De Grey Lodge, De Grey Road, Woodhouse Lane, Leeds.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Assistant Locomotive Superintendent, North Western Railway, Saharunpur, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1882. Jones, Samuel Gilbert, Hatherley Court, Gloucester.

1887. Jones, Thomas, Central Board School, Deansgate, Manchester.

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: 3 Northumberland Avenue, Putney: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1880. Joy, David, 8 Victoria Chambers, 15 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1889. Kanthack, Ralph, Sub-Manager, Carl Zeiss' Optical Works, Jena, Germany.

1888. Kapteyn, Albert, Westinghouse Brake Co., Canal Road, York Road, King's Cross, London, N.

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham. [*Globe, Birmingham.*]

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Westbromwich.

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1879. Kennedy, Professor Alexander Blackie William, F.R.S., 3 Prince's Street, Westminster, S.W.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Parkhill, Wetherby.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1888. Kershaw, Frederic, Evans y Livock, 228 Calle Piedad, Buenos Aires, Argentine Republic.

1866. Kershaw, John, Marazion, St. Leonard's-on-Sea.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1887. Key, Alexander, 36A City Buildings, Old Hall Street, Liverpool.

1885. Keydell, Amandus Edmund, Lloyd's Register of Shipping, Dundee.

1885. Keyworth, Thomas Egerton, Ferro Carril Buenos Aires y Rosario, Campana, Buenos Aires, Argentine Republic.

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1888. Kikuchi, Kyozo, Superintendent Engineer, Hirano Spinning Mill, Osaka, Japan.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1889. Kirby, Frank Eugene, Constructing Engineer, Detroit Dry Dock Co., Detroit, Michigan, United States.

1872. Kirk, Alexander Carnegie, LL.D., Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Kowloon, Hong Kong, China: (or Melita Cottage, Denny.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, Suffolk House, 5 Laurence Pountney Hill, London, E.C.

1889. Knap, Conrad, 11 Queen Victoria Street, London, E.C.

1886. Knight, Charles Albert, Babcock and Wilcox Boiler Co., 107 Hope Street. Glasgow.

1889. Knox, James, Civil and Mechanical Engineer, Auckland, New Zealand: (or care of E. D. Knox, 53 Belsize Park Gardens, South Hampstead, London, N.W.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1878. Lambourn, Thomas William, Naughton Hall, near Bildeston, S.O., Suffolk.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)

1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, Engineer-in-Chief, Midland Railway, Derby.

1879. Lapage, Richard Herbert, 17 Austin Friars, London, E.C. [*Lapage, London.*]

1888. Latham, Baldwin, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Layborn Patterson and Co., Dutton Street, Liverpool.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1889. Leaf, Henry Meredith, Messrs. Crompton and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1865. Ledger, Joseph, 7 North Terrace, Darlington.

1886. Lee, Charles Eyre, 18 Newhall Street, Birmingham.

1887. Lee, Cuthbert Ridley, Messrs. J. Coates and Co., Suffolk House, Laurence Pountney Hill, London, E.C.

1862. Lee, J. C. Frank, 9 Park Crescent, Portland Place, London, W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1883. Lennox, John, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1858. Leslie, Andrew, Coxlodge Hall, Newcastle-on-Tyne.

1888. Leslie, Sir Bradford, K.C.I.E., Tarrangower, Willesden Lane, Brondesbury, London, N.W.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1884. Lewis, Henry Watkin, Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1887. Lewis, Rowland Watkin, Messrs. Edwin Lewis and Sons, Britannia Boiler Tube Works, Wolverhampton.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]; and 7 Eastcombe Villas, Charlton Road, Blackheath, London, S.E.

1887. Lindsay, Joseph, Messrs. Urquhart Lindsay and Co., Blackness Foundry, Dundee.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.; and 3 St. John's Park, Blackheath, London, S.E.

1885. Lister, Frank, Messrs. Wilkinson and Lister, Bradford Road Works, Keighley.

1887. Litster, David Michael, Executive Engineer, Public Works Department, India; care of Messrs. Grindlay and Co., 55 Parliament Street, Westminster, S.W.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Livesey, James, 29, 30, and 31 Broad Street Avenue, London, E.C.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Normal School of Science, South Kensington, London, S.W.

1867. Lloyd, Charles, New Athenæum Club, 26 Suffolk Street, Pall Mall, London, S.W.

1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury [*Steel, Wednesbury*]; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1879. Lockhart, William Stronach, 67 Granville Park, Blackheath, London, S.E.

1881. Lockyer, Norman Joseph, care of Sir A. M. Rendel, 8 Great George Street, Westminster, S.W.

1884. Logan, Andrew Linton, Vulcan Foundry, Newton-le-Willows, Lancashire.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, 2 Charleville Road, North Circular Road, Dublin.

1887. Lorrain, James Grieve, Norfolk House, Norfolk Street, London, W.C. [*Lorrain, London.*]

1888. Low, David Allan, Lecturer on Engineering, The People's Palace Technical Schools, Mile End Road, London, E.

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1885. Low, Robert, Eildon House, Macaulay Road, Clapham Common, London, S.W.

1884. Lowcock, Arthur, Coleham Foundry, Shrewsbury.

1884. Lowdon, John, General Manager, Barry Graving Dock and Engineering Co., Exchange Buildings, Cardiff. [*Bardock, Cardiff.*]

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]

1887. Loynd, John Shaw, Messrs. Clayton Goodfellow and Co., Atlas Works, Park Road, Blackburn.

1873. Lucas, Arthur, 27 Bruton Street, New Bond Street, London, W.

1889. Lucy, Arthur John, Messrs. Turner Morrison and Co., Sugar Works, Cossipore, Calcutta, India.

1889. Lundon, Robert, 66 Elizabeth Street, Melbourne, Victoria.

1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 6 De Grey Road, Leeds. [*Arnold Lupton, Leeds.* 330.]

1887. Lupton, Kenneth, 6 Gordon Terrace, Cope Street, Coventry.

1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1889. Macallan, George, Works Manager, Great Eastern Railway, Stratford Works, London, E.

1888. Macbeth, John Bruce King, 44 Tamarind Lane, Bombay, India: (or care of Norman Macbeth, Heaton, Bolton.)

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.

1884. MacCarthy, Samuel, 6 Endwell Road, Brockley, London, S.E.

1877. MacColl, Hector, Messrs. MacIlwaine and MacColl, Ulster Iron Works, Belfast.

1879. Macdonald, Augustus Van Zandt, District Manager, New Zealand Railways, Napier, New Zealand.

1889. Macdonald, James Alexander, Broad Oaks Iron Works, Chesterfield.

1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 40 Chancery Lane, London, W.C.; and Northfield, Oxford Road, Upper Teddington, S.O., Middlesex.

1875. Maclagan, Robert, care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.

1889. MacLay, Alexander, Professor of Mechanical Engineering, Glasgow and West of Scotland Technical College, 38 Bath Street, Glasgow.

1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock.

1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1888. Macleod, Arthur William, Messrs. John Fowler and Co., 5 Mangoe Lane, Calcutta, India.

1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokio, Japan.

1865. Macnee, Daniel, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W. [*Macnee, London.*]; and Rotherham.

1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*James Maginnis, London.*]

1873. Mair-Rumley, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Screwcock, London.*]

1884. Mais, Henry Coathupe, 61 Queen Street, Melbourne, Victoria.

1888. Maitland, Eardley, Major-General, R.A., 111 New Bond Street, London, W.

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1888. Mano, Bunji, Professor of Mechanical Engineering, Imperial University, Tokyo, Japan.

1875. Mansergh, James, 3 Westminster Chambers, 5 Victoria Street, Westminster, S.W.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds. [*Maclea, Leeds.*]

1878. Marié, Georges, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1888. Marks, George Croydon, 13 Temple Street, Birmingham. [*Pumps, Birmingham.*]

1884. Marquand, Augustus John, Pierhead Chambers, Cardiff.

1887. Marriott, William, Engineer and Locomotive Superintendent, Eastern and Midlands Railway, Melton Constable, Norfolk.

1887. Marsden, Benjamin, Messrs. S. Marsden and Son, Screw-Bolt and Nut Works, London Road, Manchester.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred (*Life Member*), 13 Ferron Road, Clapton, London, E.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge [*Marten, Stourbridge.*]; Pedmore, Stourbridge; and 4 Storey's Gate, Westminster, S.W.

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. Martin, Henry, Enderley, Lodge Road, Southampton.

1888. Martin, Henry James, Castle Foundry and Engineering Works, Strand, Swansea; and Tresleigh House, Walters Road, Swansea.

1889. Martin, The Hon. James, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia.

1880. Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.

1884. Massey, George, Post Office Chambers, Pitt Street, Sydney, New South Wales.

1876. Mather, John, 4 Great George Street, Westminster, S.W. [3002]; and 23 Devonshire Road, South Lambeth, London, S.W.

1867. Mather, William, M.P., Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.)

1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.

1836. Matthews, Robert, Parrs House, Heaton Mersey, near Manchester.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, 4 Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C. [3663.]

1884. Maxim, Hiram Stevens, Maxim Nordenfelt Guns and Ammunition Co., Victoria Mansions, 32 Victoria Street, Westminster, S.W.

1859. Maylor, William, Chesterleigh, Albemarle Road, Beckenham.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1872. McConnochie, John, Engineer to the Bute Harbour Trust, 16 Bute Crescent, Bute Docks, Cardiff.

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.; and The Cedars, Norwood Green, Southall.

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]

1889. McIntyre, John Henry A., Lecturer on Mechanical Engineering, Allan Glen's School, Glasgow.

1881. McKay, John, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1888. McLaren, Henry, Messrs. J. and H. McLaren, Midland Engine Works, Leeds.

1882. McLaren, Raynes Lauder, 6 Grote's Place, Blackheath, London, S.E.

1888. McLarty, Farquhar Matheson, Penang Foundry, Penang: (or care of William Bow, Thistle Engine Works, Paisley.)
1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.
1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Glasgow.*]
1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts. United States.
1881. Meik, Charles Scott, care of H.B.M. Consul, Yokohama, Japan: (or care of P. Walter Meik, 16 Victoria Street, Westminster, S.W.)
1858. Meik, Thomas, 21 York Place, Edinburgh.
1887. Melhuish, Frederick, Assistant Engineer, Southwark and Vauxhall Water Works, 68 Sumner Street, Southwark, London, S.E.
1888. Melville, William Wilkie, 72 Outgang Lane, Nottingham.
1878. Menier, Henri, 56 Rue de Châteaudun, Paris.
1876. Menzies, William, Messrs. Menzies and Co., 50 Side, Newcastle-on-Tyne. [*William Menzies, Newcastle-on-Tyne. G.P.O.* 200. *Nor. Dis.* 1144.]
1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]
1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.
1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.
1884. Middleton, Reginald Empson, 49 Parliament Street, Wetsminster, S.W.
1886. Midelton, Thomas, Wallcroft, Randwich, Sydney, New South Wales.
1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.
1887. Miles, Frederick Blumenthal, Messrs. Bement Miles and Co., Callowhill and Twenty-first Streets, Philadelphia, United States.
1889. Miller, Adam, 205 Mansion House Chambers, 11 Queen Victoria Street, London, E.C.
1885. Miller, Harry William, care of Messrs. Chester and Gibb, Johannesburg, Transvaal, South Africa.
1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.
1887. Miller, Thomas Lodwick, University College, Liverpool.
1885. Millis, Charles Thomas, Technical College, Finsbury, London, E.C.

1887. Milne, William, Locomotive Superintendent, Natal Government Railways, Natal.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Sir Guilford Lindsay, K.C.I.E., Cliefden, Eltham.

1882. Molesworth, James Murray, Shawclough, near Rochdale: (or care of Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.)

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1885. Monk, Edwin, care of Josiah McGregor, Crown Buildings, 78 Queen Victoria Street, London, E.C.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S. O., Kent.

1876. Moore, Joseph, 1099 Adeline Street, Oakland, San Francisco, California; (or care of Ralph Moore, Government Inspector of Mines, 13 Clairmont Gardens, Glasgow.)

1872. Moorsom, Warren Maude, Belvidere, Park Road, West Dulwich, London, S.E.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1889. Morgan, David John, Central Engineering Works, Cardiff.

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1887. Morison, Donald Barns, Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1888. Morris, Charles, 5 Mangoe Lane, Calcutta, India.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1885. Morse, Harold, care of Sydney Morse, 4 Fenchurch Avenue, London, E.C.: (or Park, Nottingham.)

1858. Mountain, Charles George, Eagle Foundry, Broad Street, Birmingham.

1886. Mountain, William Charles, Messrs. Ernest Scott and Co., Close Works, Newcastle-on-Tyne; and 9 St. George's Terrace, Jesmond, Newcastle-on-Tyne.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 75 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 37 Cross Street, Manchester. [1027.]

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1889. Münster, Bernard Adolph, Engineer, Yokosuka, near Yokohama, Japan.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1863. Musgrave, John, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1888. Myers, William Beswick, 14 Victoria Street, Westminster, S.W.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1889. Nash, Thomas, Fitzalan Chambers, Sheffield; and Guzerat House, Nether Edge, Sheffield.

1888. Nathan, Adolphus, Messrs. Larini Nathan and Co., Milan; and 15 Via Bigli, Milan, Italy.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, 16 The Banks, High Street, Rochester.

1889. Needham, Joseph Edward, Patent Office, 25 Southampton Buildings, London, W.C.

1863. Neilson, Walter Montgomerie, Clyde Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1884. Nelson, John, 48 Bootham, York.

1887. Nelson, Sidney Herbert, Messrs. Samuel Worssam and Co., Oakley Works, King's Road, Chelsea, London, S.W.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, 16 Broad Street, Birmingham. [*Nettlefolds, Birmingham.*]

1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.

1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)

1884. Nicholls, James Mayne, Locomotive Superintendent, Nitrate Railways. Iquique, Chili.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1877. Nicolson, Donald, 16 St. Helen's Place, London, E.C.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 43 York Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, Maxim Nordenfelt Guns and Ammunition Co., Victoria Mansions, 32 Victoria Street, Westminster, S.W.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1883. North, Gamble, Messrs. North and Jewel, Peruano Nitrate of Soda and Iodine Works, Iquique, Chile: (or care of John T. North, Avery House, Avery Hill, Eltham.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; Woolpack Buildings, 3 Gracechurch Street, London, E.C.; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1888. Norton, William Eardley, 8 Great George Street, Westminster, S.W.

1882. Nunneley, Thomas, 9 Beech Grove Terrace, Leeds.

1885. Oakes, Sir Reginald Louis, Bart., York Engineering Works, Leeman Road, York.

1887. O'Brien, Benjamin Thompson, 45 Fern Grove, Liverpool.

1887. O'Brien, John Owden, Messrs. W. P. Thompson and Co., Ducie Buildings, 6 Bank Street, Manchester.

1868. O'Connor, Charles, 15 Wesley Street, Waterloo, near Liverpool.

1888. O'Donnell, John Patrick, 2 Great George Street, Westminster, S.W.; and Cambridge Road, New Malden, S.O., Surrey. [*ODonnell, London.*]

1887. O'Flyn, John Lucius, Messrs. L. and H. Guéret and Co., Exchange, Cardiff.

1889. Ogden, Fred, Patent Office, 25 Southampton Buildings, London, W.C.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C. [*Oaktree, London.*]

1887. Oliver, Hedley, 6 Park Hill Road, Harborne, Birmingham.

1882. Orange, James, Surveyor General's Department, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield. [*Osborn, Sheffield.*]

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1889. Owen, Thomas, Midland Railway, Derby.

1886. Owen, Thomas Henry, 200 Newport Road, Cardiff.

1868. Paget, Arthur, Loughborough. [*Paget Company, Loughborough.*]

1877. Panton, William Henry, General Manager, Tees Side Iron and Engine Works, Middlesbrough. [*Teesside, Middlesbrough.*]

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.

1872. Parker, Thomas, Locomotive Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1888. Parker, Thomas, Jun., Locomotive Department, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Persehouse, care of Messrs. Henry Persehouse Parkes and Co., 7 Goree Piazzas, Liverpool. [*Persehouse, Liverpool.*]

1884. Parlane, William, Hong Kong Ice Works, Eastpoint, Hong Kong, China.

1886. Parry, Alfred, Messrs. Balmer Lawrie and Co., 103 Clive Street, Calcutta, India.

1889. Parry, Evan Henry, Chief Engineer, South Wales and Monmouthshire Boiler Insurance Co., 10 Fisher Street, Swansea.

1878. Parsons, The Hon. Richard Clere, Oak Lea, Wimbledon Park, Surrey.

1886. Passmore, Frank Bailey, Mansion House Chambers, 11 Queen Victoria Street, London, E.C. [*Knarf, London.*]

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, Messrs. Willans and Robinson, Ferry Works, Thames Ditton.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1847. Peacock, Richard, M.P., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1879. Pearce, George Cope, Ryefields, Ross.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India.

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 47 Gunterstone Road, West Kensington, London, W.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1883. Peck, Walter, Government Inspector of Machinery, Auckland, New Zealand: (or care of Messrs. J. H. Peck and Co., Wallgate, Wigan.)

1888. Peel, Charles Edmund, Quay Parade, Swansea.

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, London, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Healey Terrace, Fairfield, near Manchester.

1882. Perry, Alfred, Messrs. Chance Brothers and Co., Lighthouse Works, near Birmingham.

1865. Perry, William, Claremont Place, Wednesbury.

1882. Petherick, Vernon, Messrs. Petherick and Co., Elevator and Hydraulic Engineers, Box 1046, General Post Office, Sydney, New South Wales.

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Henry Parnham, Assistant Locomotive Superintendent, Burma State Railway, Yamethin, Upper Burma.

1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, Kimberley, South Africa; and care of H. Eckstein, Box 149, Johannesburg, Transvaal, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E. [*Phicycle, London.*]

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [*Piercy, Birmingham.* 20.]

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1888. Pirrie, Norman, Ellerslie, Ryton-on-Tyne, R.S.O., Co. Durham.

1888. Pirrie, William James, Messrs. Harland and Wolff, Belfast.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1887. Place, John, Jun., The Bank, Church Street, Mansfield.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1888. Pogson, Joseph, Manager and Engineer, Huddersfield Corporation Tramways, Huddersfield.

1886. Pollock, James, Fenchurch House, 5 and 7 Fenchurch Street, London, E.C. [*Specific, London.*]

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 117 Camberwell Grove, London, S.E.

1878. Powell, Henry Coke, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield. [*Preston, Kirkburton.*]

1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C. [*Indices, London.* 1533.]

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.

1889. Price, John Bennett, Messrs. Stevenson and Co., Canal Foundry, Preston.

1859. Price-Williams, Richard, 38 Parliament Street, Westminster, S.W. [*Spandrel, London.*]

1886. Price-Williams, Seymour William, 38 Parliament Street, Westminster, S.W. [*Spandrel, London.*]

1874. Prosser, William Henry, Messrs. Harfield and Co., Blaydon-on-Tyne.

1885. Pudan, Oliver, Chief Engineer's Office, Cambria Iron Works, Johnstown, Pennsylvania, U.S.: (or 15 Princes Street, Yeovil.)

1884. Puplett, Samuel, 5 Thornbury Road, Clapham Park, London, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1887. Pyne, Thomas Salter, care of H.H. the Ameer of Afghanistan, Cabul; care of Messrs. Walsh Lovett and Co., Calcutta, India.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]

1885. Rainforth, William, Jun., Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]

1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C. [*Repairs, London.*]

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.

1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.

1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]

1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]

1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich. [*Waterside, Ipswich.*]

1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, 9 Victoria Street, Westminster, S.W. [*Ransomes, Westminster.*]

1888. Rapley, Frederick Harvey, Messrs. J. E. and M. Clark and Co., Dashwood House, London, E.C.

1889. Ratcliffe, James Thomas, Fabric von Izr. K. Poznanski, Lodz, Russian Poland.

1883. Rathbone, Edgar Philip, Messrs. Bewick Moreing and Alford, Box 563, Johannesburg, Transvaal, South Africa: (or care of Messrs. Bewick and Moreing, Suffolk House, Laurence Pountney Hill, London, E.C.

1867. Ratliffe, George, 81 Cannon Street Buildings, 139 Cannon Street, London, E.C.

1862. Ravenhill, John R., Delaford, Iver, near Uxbridge.

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1887. Readhead, Robert, Messrs. John Readhead and Co., West Docks, South Shields.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, Suffolk House, Laurence Pountney Hill, London, E.C. [*Wagon, London.*]

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1889. Rendell, Alan Wood, Locomotive Carriage and Wagon Superintendent, Eastern Bengal State Railway, Kanchrapara, Bengal, India: (or Ravenswood, Byculla Park, Enfield.)

1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1883. Rennert, Theodore, Box 209, Kimberley, South Africa; Box 92, Johannesburg, Transvaal, South Africa: (or care of Messrs. Findlay Durham and Brodie, 61 St. Mary Axe, London, E.C.)

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Wardha Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India.

1882. Rhodes, Vincent, Manager, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, near Sydney, New South Wales: (or care of Mrs. E. A. Rhodes, 5 Ainger Terrace, St. Catherine's Road, Grantham.)

1866. Richards, Edward Windsor, Low Moor Iron Works, near Bradford.

1882. Richards, George, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester. [*Richards, Altrincham.*]

1884. Richards, Lewis, Dowlais Iron and Steel Works, Dowlais.

1863. Richardson, The Hon. Edward, C.M.G., Wellington, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1887. Richardson, Thomas, Jun., Messrs. T. Richardson and Sons, Hartlepool Engine Works, Hartlepool.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1884. Riches, Charles Hurry, Assistant Locomotive Superintendent, Taff Vale Railway, Cardiff.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1889. Richmond, Joseph, New Sun Iron Works, Burdett Road, Bow, London, E.; and 30 Kirby Street, Hatton Garden, London, E.C.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1887. Riekie, John, District Locomotive Superintendent, North Western Railway, Hirokh, Beluchistan, India.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1884. Ripper, William, Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1889. Riva, Enrico, Locomotive and Carriage Superintendent, Rete Adriatica, Ferrovie Meridionale, Florence, Italy.

1879. Rixom, Alfred John, 1 Gordon Villas, Park Road, Loughborough.

1887. Roberts, Thomas, Locomotive Engineer, Government Railways, Adelaide, South Australia.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1887. Roberts, William, Argentine Great Western Railway, Mendoza, Argentine Republic.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Herbert J. Stockton, 16 Philpot Lane, London, E.C.)

1883. Robins, Edward, 105 Regent Street, London, W.

1874. Robinson, Henry, Professor of Surveying and Civil Engineering, King's College, Strand, London, W.C.; and 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and Westwood Hall, Leek, near Stoke-upon-Trent.

1886. Robinson, John, Barry Dock and Railways, Barry, near Cardiff.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1888. Rock, John William, Kent Street, Sydney, New South Wales.

1879. Rodger, William, care of Messrs. C. H. B. Forbes and Co., 3 Elphinstone Circle, Bombay: (or care of Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.)

1884. Rodrigues, José Maria de Chermont, Rua de S. Pedro 54 sobrado, Rio de Janeiro, Brazil: (or care of Messrs. Jacob Walter and Co., Billiter Square Buildings, London, E.C.)

1872. Rofe, Henry, 8 Victoria Street, Westminster, S.W.

1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1889. Rosenthal, James Hermann, Babcock and Wilcox Boiler Co., 114 Newgate Street, London, E.C.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1888. Rowan, James, Messrs. David Rowan and Son, Elliot Street, Glasgow.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, General Manager, Wallsend Pontoon Works, Bute Docks, Cardiff. [*Wall, Cardiff.*]

1877. Rutter, Edward, The Cedars, Richmond, Surrey.

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton. [*Ryder, Bolton.* 33A.]

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1859. Sacré, Charles Reboul, Consulting Engineer, Manchester Sheffield and Lincolnshire Railway, Manchester; 18 Fountain Street, Manchester; and Sunnyside, Victoria Park, Manchester.

1883. Sadoine, Baron Eugène, 57 Rue des Augustins, Liége, Belgium.

1864. Saïd, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 9 Park Crescent, Portland Place, London, W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford and 23 St. Ermin's Mansions, Westminster, S.W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and Elm Lodge, Southall.

1871. Sanders, Richard David, Hillside House, Berkhamsted.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.*]; and Cold Harbour Lawn, Wivelsfield, near Burgess Hill, S.O., Sussex.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1886. Scholes, William Henry, 1255 n/n Rivadavia, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 4 Rosebery Road, Brixton, London, S.W.

1880. Schram, Richard, 17A Great George Street, Westminster, S.W. [*Schram, London.*]

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Lyncot, Romford.

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.)

1882. Scott, Charles Herbert, Bessemer Steel Works, Sheffield.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1881. Scott, George Innes, 9 Queen Street, Newcastle-on-Tyne.

1877. Scott, Irving M., Union Iron Works, San Francisco, California.

1881. Scott, James, Umlaas Wool-Scouring Works, Durban, Natal: (or Douglasfield, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1885. Scott, Robert, Engineer, Messrs. Takata and Co., 88 Bishopsgate Street Within, London, E.C.

1861. Scott, Walter Henry, Locomotive Superintendent, Great Southern Railway, Buenos Aires, Argentine Republic: (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1884. Scott-Moncrieff, William Dundas, 86 Newman Street, Oxford Street, London, W.

1868. Scriven, Charles, Whinfield Mount, Chapel Allerton, Leeds. [*Scriven, Leeds.*]

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1886. Seddon, Robert Barlow, Manager, Wigan Wagon Works, Wigan.

1882. Selfe, Norman, 141 Pitt Street, Sydney, New South Wales.

1884. Sellers, Coleman, E.D., Professor of Engineering, Stevens Institute, and Franklin Institute; 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1888. Sellers, George, Holly Cottage, Wakefield.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1889. Selman, David Codrington, Professor of Mathematics, University College, Bristol.

1881. Sennett, Richard, Messrs. Maudslay Sons and Field, Lambeth, London, S.E.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah; and 7 Hastings Street, Calcutta.

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1863. Sharp, Henry, Townend House, Deepear, Sheffield.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.

1869. Sharrock, Samuel, Green Bank, Long Lane, Grassendale, Liverpool.

1882. Sharrock, Samuel Lord, New South Wales Club, Sydney, New South Wales.

1879. Shaw, Henry Selby Hele, Professor of Engineering, University College, Liverpool.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Messrs. W. Shaw Kirtley and Co., Wellington Cast Steel Foundry, Middlesbrough.

1856. Shelley, Charles Percy Bysshe, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, Resident Engineer, Lake Aboukir Reclamation Works, near Alexandria, Egypt: (or 89, Westbourne Terrace, Hyde Park, London, W.)

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1888. Shin, Tsuneta, 41 Kanetomicho, Koishikawa, Tokyo, Japan.

1889. Shone, Isaac, Great George Street Chambers, Westminster, S.W.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1888. Siemens, Frederick, 10 Queen Anne's Gate, Westminster, S.W.

1888. Siemens, Dr. Werner, Messrs. Siemens and Halske, 94 Markgrafen Strasse, Berlin.

1871. Simon, Henry, 20 Mount Street, Manchester. [*Reform, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1878. Simpson, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1885. Simpson, James Thomas, Executive Engineer, Public Works Department, Shwebo, Upper Burmah.

1882. Simpson, John Harwood, Manchester Ship Canal, 65 King Street, Manchester.

1889. Sinclair, Nisbet, Messrs. Robert Napier and Sons, Lancefield House, Glasgow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1881. Sisson, William, Quay Street Iron Works, Gloucester. [*Sisson, Gloucester.*]

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 25 Royal York Crescent, Clifton, Bristol.

1885. Slight, William Hooper, Woodborough Vicarage, Nottingham.

1886. Small, James Miln, 4 The Sanctuary, Westminster, S.W.

1889. Smelt, John Dann, Argentine Great Western Railway, 4 Finsbury Circus, London, E.C.

1879. Smith, Allison Dalrymple, Assistant Locomotive Superintendent, Locomotive Workshops, Victorian Railways, Newport, Victoria.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1866. Smith, Edward Fisher, 34 Avenue Road, Regent's Park, London, N.W.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, Sir John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness; and Rhine Hill, Stratford-on-Avon.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax; and 18 Abingdon Street, Westminster, S.W. [*Outfall, London.*]

1886. Smith, Reginald Arthur, Messrs. Dorman and Smith, 24 Brazenose Street, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 124 Hagley Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1887. Smith, William Mark, District Locomotive Carriage and Wagon Superintendent, Great Southern and Western Railway, Cork.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, F.R.S., West Cumberland Iron and Steel Works, Workington.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W. [*Sopwith, London.* 3175.]

1887. Sorabji, Shapurji, Bombay Foundry and Engine Works, Khetwady, Bombay: (or care of Messrs. S. and E. Ransome and Co., 10 Essex Street, Strand, London, W.C.)

1884. Soulsby, James Charlton, 17 Mount Stuart Square, Cardiff.

1889. Souter-Robertson, David, West's Patent Press Co., Saharanpore, North Western Provinces, India.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres, Francis Johnstone de, 6 Arlington Villas, Clifton, near Bristol.

1887. Spence, William, Cork Street Foundry and Engineering Works, Dublin.

1887. Spencer, Alexander, 77 Cannon Street, London, E.C.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Globe Tube Works, Wednesbury [*Tubes, Wednesbury.*]; and 3 Queen Street Place, Cannon Street, London, E.C. [*Tubes, London.*]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Ardwick, Manchester; and The Meadows, Alderley Edge, near Manchester.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirokh, Beluchistan, India.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, Chemical Laboratory and Testing Works, Broadway, Westminster, S.W.

1888. Stanley, Harry Frank, Messrs. Pontifex and Wood, Farringdon Works, Shoe Lane, London, E.C.; and 84 Finsbury Park Road, London, N.

1888. Stannah, Joseph, 20 Southwark Bridge Road, London, S.E.

1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W. [*Precursor, London.*]

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, London, E.C. [*Fluvius, London.*]

1888. Stephenson-Peach, William John, Trent Fish Culture Co., Milton, Burton-on-Trent.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*]; and 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1887. Stevenson, David Alan, F.R.S.E., 84 George Street, Edinburgh.

1878. Stevenson, George Wilson, 38 Parliament Street, Westminster, S.W.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1887. Stewart, Andrew, 41 Oswald Street, Glasgow.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]

1885. Stewart-Hamilton, Patrick, care of Rev. Alexander Hamilton, D.D., The Manse, Brighton.

1888. Stiff, William Charles, Credenda Seamless Steel-Tube Works, Ledsam Street, Birmingham.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1888. Stirling, Robert, North Eastern Railway, Locomotive Department, Gateshead.

1875. Stoker, Frederick William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent.

1877. Stokes, Alfred Allen, Elmcote, Godalming.

1887. Stone, Frank Holmes, Callulut, Manila, Manila and Dagupan Railway, Manila, Philippine Islands: (or care of Messrs. Hett Maylor and Co., 53 New Broad Street, London, E.C.)

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1888. Strachan, James, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Nottingham.

1888. Straker, Sidney, 240 Stanstead Road, Forest Hill, London, S.E.

1884. Stronge, Charles, Locomotive Department, Porto Alegre and New Hamburg Railway, São Leopoldo, Rio Grande do Sol, Brazil: (or 1 Albion Street, Hyde Park, London, W.)

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow [*Strype, Wicklow.*]; 1 College Street, Dublin; and Park Avenue, Sydney Parade, near Dublin.

1878. Stuart, James, M.P., Professor of Mechanism in Cambridge University, Trinity College, Cambridge.

1889. Stuart-Hartland, Dare Arthur, Messrs. Balmer Lawrie and Co., 103 Clive Street, Calcutta, India.

1882. Sturgeon, John, Shrublands, Hoole Road, Chester.

1882. Sugden, Thomas, Chadderton Iron Works, Irk Vale, Chadderton, near Oldham; and 10 Mark Lane, London, E.C.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, Messrs. Willans and Robinson, Ferry Works, Thames Ditton, Surrey.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1887. Suverkrop, John Peter, 1 Kew Gardens Road, Kew, Surrey.

1882. Swaine, John, Messrs. Wright Butler and Co., Panteg Steel Works, near Newport, Monmouthshire.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.; and Lauriston, Bromley, Kent.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and The Corner House, Shortlands, S.O., Kent.

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe; and 4 Wellington Villas, Wellington Square, Crewe.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1876. Taunton, Richard Hobbs, Messrs. Taunton Delmard Lane and Co., Star Tube Works, Heneage Street, Birmingham. [*Taunton, Birmingham.*]

1882. Tayler, Alexander James Wallis, 77 Victoria Road, Kilburn, London, N.W.

1874. Taylor, Arthur, Manager, Lahat Tin Mines, Perak, viâ Penang; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1887. Taylor, James, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, 26 Rue de Caumartin, Paris.

1882. Taylor, Robert Henry, 55 Kent House Road, Sydenham, London, S.E.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, Messrs. Renshaw King and Co., Kidsgrove, near Stoke-on-Trent.

1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.

1889. Thomas, James Donnithorne, 25A Old Broad Street, London, E.C.

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1888. Thomas, Philip Alexander, Mirrlees. Watson and Yaryan Co., 45 Scotland Street, Glasgow.

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1880. Thompson, Thomas William, Eastham Ferry Pier, near Birkenhead.

1887. Thompson, William Phillips, 6 Lord Street, Liverpool.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1889. Thomson, Robert McNidar, Yokohama Engine and Iron Works, Kobe, Japan.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Horwich, near Bolton.

1888. Thornton, Robert Samuel, West's Patent Press Co., Etawah, North Western Provinces, India.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Engineer, New South Wales Government Railways, Eveleigh Workshops, Sydney, New South Wales: (or care of Joseph Meilbek, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford. [*Thwaites, Bradford.* 325.]

1887. Thwaites, Edward Hirst, Messrs. Thwaites Brothers, Vulcan Iron Works, Bradford.

1885. Tijou, William, 38 Orchard Road, Highgate, London, N.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium. [*Société Meuse, Liége.*]

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 38 Croom's Hill, Greenwich, London, S.E.

1888. Todd, Robert Ernest, Mechanical Engineer, La Madrid, Ferro Carril National Central Norte, Argentine Republic: (or care of William H. Todd, County Buildings, Land of Green Ginger, Hull.)

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow; and 2 Victoria Mansions, 28 Victoria Street, Westminster, S.W.

1857. Tomlinson, Joseph, Jun., 64 Priory Road, West Hampstead, London, N.W.

1888. Topple, Charles James, Machinery Department, Royal Arsenal, Woolwich.

1883. Tower, Beauchamp, 5 Queen Anne's Gate, Westminster, S.W.

1889. Towler, Alfred, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1888. Travis, Henry, Machinery Department, Royal Arsenal, Woolwich.

1889. Trenerry, William Penrose, 21 Via Cavour, Florence, Italy. [*Trenerry, Firenze.*]

1883. Trentham, William Henry, 2 Hervey Road, Shooter's Hill Road, London, S.E.

1876. Trevithick, Richard Francis, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1886. Trew, James Bradford, High Street, Watford, Herts.

1887. Trier, Frank, Messrs. Brunton and Trier, 19 Great George Street, Westminster, S.W.

1885. Trueman, Thomas Brynalyn, Ferro Carril Buenos Aires al Pacifico, Junin, Argentine Republic: (or care of Thomas R. Trueman, 7 Cambridge Villas, Twickenham.)

1887. Turnbull, Alexander, Messrs. Alexander Turnbull and Co., St. Mungo Works, Bishopbriggs, Glasgow.

1885. Turnbull, John, Jun., 255 Bath Street, Glasgow. [*Turbine, Glasgow.*]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1886. Turner, George Reynolds, Vulcan Iron Works, Langley Mill, near Nottingham; and 81 Highgate Road, London, N.W.

1887. Turner, Joshua Alfred Alexander, Superintendent and Chief Engineer, Government Steam Flour Mills, Poona, India.

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, Sir John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 2 Newgate Street, London, E.C.

1889. Tyrrell, Joseph John, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1878. Unwin, William Cawthorne, F.R.S., Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Tamboff Government, Russia.

1880. Valon, William Andrew McIntosh, Connaught Mansions, Victoria Street, Westminster, S.W.; and Ramsgate. [*Valon, Ramsgate.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Pulleys, Openshaw.*]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.; and Rothbury, Blackheath Park, London, S.E. [*Exemplar, London.*]

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1888. Voysey, Henry Wesley, 130 Maygrove Road, Brondesbury, London, N.W.

1883. Waddell, James, Superintending Engineer, Netherlands India Steam Navigation Co., Soerabaya, Java; and 13 Austin Friars, London, E.C.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, The Hon. Nowrosjee Nesserwanjee, C.I.E., Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1875. Wailes, John William, Patent Shaft Works, Wednesbury.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1888. Waister, William Henry, Assistant Locomotive Superintendent, Great Western Railway, Stafford Road Works, Wolverhampton.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds. [*Tannett Walker, Leeds.*]

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 3 Alexandra Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Matthew, 16 London Street, Fenchurch Street, London, E.C.

1886. Walker, Robert John, Church-Stile House, Shap, R.S.O., Westmoreland.

1884. Walker, Sydney Ferris, 195 Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Hunter's Forge, New Bridge Street, Newcastle-on-Tyne. [*Dynamo, Newcastle-on-Tyne.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1881. Walkinshaw, Frank, Yokohama Water Works, Yokohama, Japan: (or care of W. Walkinshaw, Hartley Grange, Winchfield.)

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 49 New Road, Grays, S.O., Essex; and 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, 58 Leopold Street, Loughborough.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham. [*Bolts, Birmingham.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1885. Warren, Henry John, Jun., Box 86, Wit Waters Randt, Johannesburg, Transvaal, South Africa: (or Hayle, Cornwall.)

1885. Warren, William, care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.

1882. Warsop, Henry, Clarendon Hotel, Nottingham.

1889. Warsop, Thomas, Coniston Copper Mines, Coniston, S.O., Lancashire.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1881. Watkins, Alfred, 2 Westcombe Park Road, Blackheath, London, S.E.

1862. Watkins, Richard, 71 Blenheim Crescent, London, W.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1884. Webb, Richard George, Messrs. Richardson and Cruddas, Bombay, India: (or care of Francis Webb, 31 Southampton Buildings, Chancery Lane, London, E.C.).

1887. Webster, William, care of Messrs. J. M. Lyon and Co., Engineers, Singapore.

1883. Week, Friedrich, Town Hall Chambers, 86 New Street, Birmingham.

1888. Wellman, Samuel T., Otis Iron and Steel Works, Cleveland, Ohio, United States.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 14 Castle Street, Liverpool.

1874. West, Nicholas James, 36 Upper Park Road, Hampstead, London, N.W.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowes, London.* 3199.]

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Bangkok, Siam: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: (or care of J. C. Mewburn, 169 Fleet Street, London, E.C.)

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1888. Weyman, James Edwardes, Messrs. Weyman and Johnson, Church Acre Iron Works, Guildford.

1881. Wharton, William Augustus, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Nottingham; and 3 Maples Street, Bentinck Road, Nottingham.

1884. Whieldon, John Henry, Campanhia do Beberibe, Rua Imperador, Pernambuco, Brazil: (or care of Ernest W. Whieldon, 42 Worlingham Road, East Dulwich, London, S.E.)

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1887. White, Alfred George, 50 Rua do Corpo Santo, Lisbon.

1874. White, Henry Watkins, 23 Leadenhall Street, London, E.C.; and 122 Lavender Hill, London, S.W.

1888. White, William Henry, F.R.S., Assistant Controller and Director of Naval Construction, Admiralty, Whitehall, London, S.W.

1885. Whitehead, James George, Mechanical Engineer, Hacienda San Nicolas, Puerto de Supe, Peru.

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds. [*Torpedo, Leeds.*]

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1888. Whittle, John, Union Railway Wagon Works, Chorley.

1878. Whytehead, Hugh Edward, North Staffordshire Tramways, Stoke-on-Trent.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of Dr. Wicks, South View House, West Parade, Newcastle-on-Tyne.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1889. Wigham, John Richardson, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1881. Wigzell, Eustace Ernest, Biliiter House, Billiter Street, London, E.C. [*Wigzell, London.* 1844.]

1882. Wilder, John, Yield Hall Foundry, Reading.

1886. Wildridge, John, Consulting Engineer and Marine Superintendent, Eastern and Australian Steamship Co., 34 Leadenhall Street, London, E.C.; and care of Messrs. Gibbs Bright and Co., Pitt Street, Sydney, New South Wales.

1888. Willans, Peter William, Messrs. Willans and Robinson, Ferry Works, Thames Ditton, Surrey. [*Willans, Thamesditton.*]

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1883. Williams, Edward Leader, Engineer, Manchester Ship Canal Co., Manchester. [*Leader, Manchester.* 688.]

1884. Williams, John Begby, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1884. Williams, John Rhys, Rhymney Iron Works, Rhymney, R.S.O., Monmouthshire.

1885. Williams, Nicholas Thomas, 6 Great Winchester Street, London, E.C.

1847. Williams, Richard, Brunswick House, Wednesbury.

1881. Williams, William Freke Maxwell, 29 Great St. Helen's, London, E.C.

1873. Williams, William Lawrence, 16 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1889. Williams, William Walton, Jun., Mercado Central de Frutos, Buenos Aires, Argentine Republic.

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.

1870. Willman, Charles, 26 Albert Road, Middlesbrough.

1884. Willock, Capt. Harry Borlase, R.E., War Office, Whitehall, London, S.W.

1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]

1872. Wilson, Alfred, North Grange, Horsforth, near Leeds.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt; Cairo, Egypt.

1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]

1863. Wilson, John Charles, 24 Lincoln's Inn Fields, London, W.C. [*Palacol, London.*]
1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.
1880. Wilson, Robert, 10 St. Bride Street, London, E.C.; and 7 St. Andrew's Place, Regent's Park, London, N.W.
1883. Wilson, Robert, 7 Westminster Chambers, 13 Victoria Street, Westminster, S.W.
1884. Wilson, Thomas, Superintendent, General Steam Navigation Company's Works, Deptford, London, S.E.
1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)
1888. Wilson, Walter Henry, Messrs. Harland and Wolff, Belfast.
1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.
1886. Windsor, Edwin Wells, 1 Rue du Hameau des Brouettes, Rouen, France.
1887. Winmill, George, Locomotive and Carriage Superintendent, Oudh and Rohilkund Railway, Lucknow, India; and Hare Street, Romford.
1872. Winstanley, Robert, Mining Engineer, 28 Deansgate, Manchester.
1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloyd Wise, London.* 2766.]
1871. Withy, Edward, Avon Villa, Parnell, Auckland, New Zealand.
1884. Withy, Henry, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]
1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)
1878. Wolfenden, Richard, 11 Grafton Street, Moss Side, Manchester.
1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China: (or 11 Grafton Street, Moss Side, Manchester).
1888. Wolff, Gustav William, Messrs. Harland and Wolff, Belfast.
1881. Wood, Edward Malcolm, 2 Westminster Chambers, 3 Victoria Street, Westminster, S.W.
1887. Wood, Henry, Messrs. J. and E. Wood, Victoria Foundry, Bolton.
1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.
1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.
1885. Wood, Robert Henry, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds; and 15 Bainbrigge Road, Headingley, Leeds.

1884. Wood, Sidney Prescott, care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1888. Woodford, Ethelbert George, State Engineer of Mines, Pretoria, South African Republic, Transvaal.

1884. Woodward, William, Engineer and Manager, Corporation Gas Works, Bury, Lancashire. [*Woodward, Bury.*]

1885. Wootton, Albert, Falcon Engine and Car Works, Loughborough.

1887. Worger, Douglas Fitzgerald, Assistant Engineer, Southwark and Vauxhall Water Works, 68 Sumner Street, Southwark, London, S.E.

1874. Worsdell, Thomas William, Locomotive Superintendent, North Eastern Railway, Gateshead. [*Locomotive, Gateshead.*]

1884. Worssam, Charles Smith, 35 Queen Victoria Street, London, E.C.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States: (or care of the Worthington Pumping Engine Co., 153 Queen Victoria Street, London, E.C.)

1888. Worthington, Edgar, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and High Bank House, Gorton, near Manchester.

1869. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and Mill Bank, Vicarage Lane, Bowdon, R.O., near Altrincham.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Wrens, Manchester.*]

1881. Wrench, John Mervyn, District Engineer, Indian Midland Railway, Jhansi, N.W. Provinces, India.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway-Carriage and Wagon Co., Saltley Works, Birmingham; and Arundel House, Lower Road, Richmond, Surrey.

1860. Wright, Joseph, 16 Great George Street, Westminster, S.W.; and Lawnswood, Alexandra Road, Upper Norwood, London, S.E.

1878. Wright, William Barton, Rosslyn, Cleveland Road, Ealing, London, W.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1886. Wylie, James, 32 St. Matthew's Road, Smethwick, near Birmingham.

1865. Wyllie, Andrew, 1 Leicester Street, Southport.

1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works, Denbigh. [*Foundry, Denbigh.*]

1877. Wyvill, Frederic Christopher, 19 East Parade, Leeds.

1889. Yarrow, Alfred Fernandez, Isle of Dogs, Poplar, London, E.

1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, District Locomotive Superintendent, Eastern Bengal State Railway, Sealdah, Calcutta: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. York, Francis Colin, Buenos Aires and Pacific Railway, Junin, Buenos Aires, Argentine Republic: (or care of Messrs. Samuel York Sons and Co., Snow Hill, Wolverhampton.)

1889. Young, David, Messrs. Haseltine Lake and Co., 45 Southampton Buildings, London, W.C.

1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Engine and Iron Works, Fence Houses.

1879. Young, James, Low Moor Iron Works, near Bradford.

1887. Young, William Andrew, Messrs. Hawthorns and Co., Leith Engine Works, Leith.

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Zimmer, George Friedrich, care of J. Harrison Carter, 82 Mark Lane, London, E.C.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Cross George Street, Sheffield.

1880. Bagshawe, Washington, Monk Bridge Iron Works, Leeds.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland; and The Glen, Newry, Ireland.

1889. Barr, John, Glenfield Engineering Works, East Shaw Street, Kilmarnock.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1888. Brown, Harold, 2 Bond Court, Walbrook, London, E.C.

1889. Castle, Frederick George, The People's Palace Technical Schools, Mile End Road, London, E.

1889. Chamberlain, John George, Messrs. Joseph Wright and Co., Neptune Forge, Tipton.

1888. Chrimes, Charles Edward, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1887. Chubb, Edward George, Ironbridge Gas Works, Ironbridge, R.S.O., Shropshire.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 18 St. Dunstan's Hill, London, E.C.

1886. Fisher, Harry, Messrs. Burys and Co., Regent Steel Works, Sheffield.

1889. Golby, Frederick William, "Invention" Office, 54 Fleet Street, London, E.C. [*Negotiate, London.* 2669.]

1889. Götz, Carl Johann Wilhelm, Messrs. John M. Sumner and Co., 2 Brazennose Street, Manchester.

1889. Gregory, George Francis, Boarzell, Hawkhurst.

1887. Hind, Enoch, Edgar Rise, Nottingham.

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]

1882. Jackson, William, Kingston Cotton Mill, Hull. [*Cotton, Hull.*]

1884. Livesey, Joseph Montague, Stourton Hall, Horncastle.

1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.* 131.]

1883. Macilraith, James, 92 Regent Street, Glasgow. [*Macilraith, Glasgow.*]

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1889. McKinnel, William, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1889. Miles, William Henry, Town Engineer, Sanitary Board, Johannesburg, Transvaal, South Africa.

1885. Moser, Charles Henry, Messrs. Moser and Sons, 178 High Street, Southwark, London, S.E. [*Moserson, London.* 4563.]

1889. Nasmith, Joseph, 4 Arcade Chambers, St. Mary's Gate, Manchester.

1887. Neville, Edward Hermann, Messrs. Julius G. Neville and Co., Oriel Chambers, Liverpool. [*Neville, Liverpool.* 3409.]

1886. Newton, Henry Edward, 6 Bream's Buildings, Chancery Lane, London, E.C.

1888. O'Sullivan, Alfred Timothy, 13 Henrietta Street, Swansea.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]

1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.

1888. Peake, Robert Cecil, Stoke Lodge, Bletchley.

1887. Peech, Henry, Phœnix Bessemer Steel Works, near Sheffield.

1887. Peech, William Henry, Phœnix Bessemer Steel Works, near Sheffield.

1884. Phillips, Richard Morgan, 21 to 24 State Street, New York, United States. [*Sarita, New York.*]

1886. Raven, Henry Baldwin, Messrs. Hare and Co., Temple Chambers, Temple Avenue, London, E.C.

1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.

1888. Rowell, John Henry, New Brewery, High Street, Gateshead.

1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1887. Scott, Walter, Victoria Chambers, Grainger Street West, Newcastle-on-Tyne. [*Contractor, Newcastle-on-Tyne.*]

1878. Stalbridge, The Right Hon. Lord, 12 Upper Brook Street, Grosvenor Square, London, W.

1886. Stumore, Frederick, 34 Leadenhall Street, London, E.C.

1884. Tilfourd, George, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1887. Tozer, Edward Sanderson, Phœnix Bessemer Steel Works, near Sheffield.

1888. Tucker, Thomas, Messrs. Isaac Tucker and Co., Turk's Head Brewery, Gateshead.

1869. Varley, John, Leeds Forge, Leeds.

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

GRADUATES.

1884. Adam, Frank, Sir W. G. Armstrong Mitchell and Co., Elswick, Newcastle-on-Tyne; and 89 Church Street, Stoke Newington, London, N.

1885. Addis, Frederick Henry, Ajmere, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Allgood, Robert Lancelot, Nunwick, Humshaugh, R.S.O., Northumberland.

1885. Amos, Ewart Charles, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.; and The Sycamores, Beulah Hill, Upper Norwood, London, S.E.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent; and Roydon Lodge, Erith, S.O., Kent.

1882. Anderson, William, North Eastern Railway, Locomotive Department, Leeds.

1878. Appleby, Charles, Jun., 89 Cannon Street, London, E.C. [*Appleby's, London.* 1731.]

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.

1887. Ashby, Joseph Harrison, Dowlais New Furnaces, East Moors, Cardiff; and Ascot Heath, Berkshire.

1889. Ashford, John, Messrs. G. E. Belliss and Co., Ledsam Street Works, Birmingham.

1886. Atkey, Albert Reuben, Corporation Water Works, Nottingham.

1888. Bailey, Wilfred Daniel, India-rubber Gutta-percha and Telegraph Works, Casilla de Correo 1212, Buenos Aires, Argentine Republic.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1888. Barker, Eric Gordon, Guyse House, Oxton, R.O., near Birkenhead.

1889. Barrow, Arthur Robert Maclean, 13 Upper Maze Hill, St. Leonard's-on-Sea.

1882. Barstow, Thomas Hulme, Manager, Kaihu Railway, Dargaville, Auckland, New Zealand.

1888. Bell, Alexander Dirom, The Woll, Hawick.

1884. Bell, Robert Arthur, Locomotive Department, South Indian Railway, Negapatam, India: (or care of Mrs. Bell, 30 Brempton Crescent, London, S.W.)

1880. Birkett, Herbert, care of Messrs. S. G. Sansinena and Co., 64 Peru, Buenos Aires, Argentine Republic; and 62 Green Street, Grosvenor Square, London, W.

1884. Bocquet, Harry, care of Arthur E. Shaw, Estacion Central, Buenos Aires, Argentine Republic: (or care of Joseph Harrison, Llanwye, Hampton Park, Hereford.)

1883. Booth, William Stanway, Messrs. Vivian and Sons, Hafod Foundry, Swansea.

1888. Boulding, Sidney, Messrs. Green and Boulding, 21 Featherstone Street, London, E.C.

1886. Bourne, Thomas Johnstone, Formosan Railway, care of H.B.M. Consul, Amoy, China: (or care of Mrs. Bourne, Clyde Villa, Southborough, Tunbridge Wells.)

1888. Bradley, Arthur Ashworth, St. Edmund's Vicarage, Dudley, Worcestershire.

1887. Bremner, Bruce Laing, 33 London Road, Carlisle: (or Streatham House, Canaan Lane, Edinburgh.)

1878. Brooke, Arthur, General Post Office, Auckland, New Zealand: (or care of Miss Helen Brooke, Sunnymead, The Rise, Sidcup, S.O., Kent.)

1889. Brown, Arthur Selwyn, 9 Santley Street, Clapham, London, S.W.; and Sydney, New South Wales.

1880. Buckle, William Harry Ray, 1 Akenside Hill, Newcastle-on-Tyne. [*Noble, Newcastle.* 663.]

1886. Budenberg, Christian Frederick, 25 Demesne Road, Whalley Range, Manchester.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1887. Burnett, Arthur Sydney, 5 Ramsbottom Terrace, Horwich, near Bolton.

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1886. Cairnes, Frederick Evelyn, 2 Maismore Mansions, Canfield Gardens, Finchley Road, London, N.

1889. Calastremé, John Carlos, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1889. Challen, Walter Bernard, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1885. Clift, Leslie Everitt, Fernbank, Pittville, Cheltenham.

1883. Clinkskill, Alfred Alphonse Rouff, Messrs. James Clinkskill and Son, 1 Holland Place, St. Vincent Street, Glasgow.

1886. Conyers, Sidney Ward, Existing Lines Office, Railway Department, Sydney, New South Wales.

1889. Cook, George Norcliffe, Messrs. Thomas Firth and Sons, Norfolk Works, Sheffield.

1883. Cotton, Henry Streatfeild, 10 Sussex Square, Hyde Park, London, W.

1888. Cox, Herbert Henry, care of J. McLean, 20 Kelvinhaugh Street, Glasgow.

1887. Crosland, Delevante William, 22 Royal Crescent, Kensington, London, W.

1885. Crosta, Lorenzo William, Messrs. R. R. Newlove and Co., Crown Iron Works, Crocus Street, Nottingham; and 21 Mayfield Grove, Nottingham.

1875. Dawson, Edward, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1884. Dixon, John, Westley Street, Lytham, near Preston, Lancashire.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1886. Duvall, Charles Anthony, Wrekin Foundry, Wellington, Shropshire.

1885. Edwards, Walter Cleeve, Assistant Engineer, Midland Railway, Greymouth, New Zealand.

1887. England, William Henry, 40 Matlock Terrace, Leeds.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1886. Grant, Percy, Sola Works, Ferro Carri. del Sud, Buenos Aires, Argentine Republic.

1887. Hanby, Wrey Albert Edward, Assistant Engineer, Public Works Department, Bengal, India: (or care of E. T. Hanby, 34 Bassein Park Road, Shepherd's Bush, London, W.)

1889. Harrison, Gilbert Harwood, Lieutenant R.E., Assistant Inspector of Gun Carriages, Royal Arsenal, Woolwich.

1889. Hayward, Robert Francis, Messrs. Crompton and Co., Arc Works, Chelmsford.

1885. Head, Archibald Potter, 16 Rutland Street, Hampstead Road, London, N.W.

1882. Heath, Ashton Marler, care of Sir A. M. Rendel, 8 Great George Street, Westminster, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, 1 Huntly Road, Fairfield, Liverpool.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1887. Hogg, William, Cosmos Club, Buenos Aires, Argentine Republic; (or Craigmore, Blackrock, near Dublin.)

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1884. Holt, Follett, Ferro Carril Buenos Aires y Rosario, Campana, Argentine Republic: (or care of Robert Hallett Holt, 3 Devonshire Terrace, Portland Place, London, W.)

1886. Hosgood, John Howell, Locomotive and Hydraulic Superintendent, Barry Dock and Railways, Barry, near Cardiff.

1889. Hosgood, Thomas Watkin, Richardson Street, Swansea.

1889. Hosken, Arthur Fayrer, London Brighton and South Coast Railway Works, Brighton.

1889. Howard, Geoffrey, Britannia Iron Works, Bedford.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works, Regent Bridge, Salford, Manchester. [*Esluh, Manchester.*]

1887. Jones, Edward Ebden, 7 Combe Terrace, Westcombe Park, Blackheath, London, S.E.

1889. Joy, Basil Humbert, 9 Victoria Chambers, 17 Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1884. King, Charles Philip, Royston House, Upper Richmond Road, Putney, London, S.W.

1885. Laidler, Thomas, Meldon House, Leopold Street, Burdett Road, London, E. [*Gravitation, London.*]

1883. Lander, Philip Vincent, Assistant Engineer, Argentine Great Western Railway, Mendoza, Argentine Republic: (or Lyndhurst, Hampton Wick, R.O., Kingston-on-Thames.)

1881. Lawson, James Ibbs, Resident Engineer, New Zealand Railways, Invercargill, Otago, New Zealand.

1889. Legros, Lucien Alphonse, 57 Brook Green, Hammersmith, London, W.

1888. Letchford, Joseph, Manager, Messrs. David Munro and Co., Stuart Street. Melbourne, Victoria; care of Richard Speight, Glenroy Park, Hampton Street, Middle Brighton, Melbourne, Victoria: (or care of James Letchford, 370 Wandsworth Road, London, S.W.)

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff; and Llwyn-yr-eos, Abercanaid, near Merthyr Tydfil.

1886. Lucy, William Theodore, Thornleigh, Woodstock Road, Oxford.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 89, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1883. Malan, Ernest de Mérindol, Howden.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1883. Marrack, Philip, R.N., H.M.S. "Hibernia," Malta; and 11 Maristow Terrace, Saltash, R.S.O., Cornwall.

1889. Marshall, Frank Theodore, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1888. Marten, Hubert Bindon, 7 Endsleigh Terrace, Tavistock.

1882. Martindale, Warine Ben Hay, 82 New Bond Street, London, W.; and Overfield, Bickley, R. S. O., Kent.

1886. Mattos, Alvaro Gomes de, 98 Rua da Saude, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1887. May, Harold Milton, Hunslet Engine Works, Leeds.

1867. Mitchell, John, Swaithe Hall, Barnsley.

1868. Moor, William, Jun., Cross Lanes, Hetton-le-Hole, near Fence Houses.

1878. Newall, John Walker, 62 Ogden Street, Ardwick, Manchester.

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1883. O'Connor, John Frederick, 6 East Seventeenth Street, New York.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1881. Oswell, William St. John, 110 Cannon Street, London, E.C.

1889. Paget, Edgar Lyon, Messrs. A. Paget and Co., Loughborough.

1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.

1887. Paterson, John Edward, Locomotive Department, New South Wales Government Railways, Redfern Works, Sydney, New South Wales.

1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1888. Pilkington, Herbert, Tipton Green Furnaces, Tipton; and Barnfield House, Tipton.

1887. Price-Williams, John Morgan, Engineer's Office, Great Northern Railway, 7 York Road, King's Cross, London, N.

1887. Pullen, William Wade Fitzherbert, 18 Crookham Road, Fulham, London. S.W.

1884. Reynolds, Thomas Blair, 5 Great George Street, Westminster, S.W.

1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1887. Rogers, Horace Wyon, 43 Upper Thames Street, London, E.C.

1881. Rogers, Philip Powys, Assistant Engineer, Wardha Coal State Railway, Warora, Central Provinces, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1889. Roope, Walter, 10 Hillside Street, Springburn, Glasgow.

1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.

1888. Rümmele, Alfredo, 17 Via Principe Umberto, Milan, Italy.

1882. Sanchez, Juan Emilio, Talleres de Marina Nacionales, Tigre, Buenos Aires, Argentine Republic: (or care of Messrs. J. E. and M. Clark and Co., 9 New Broad Street, London, E.C.)

1881. Scott, Ernest, Close Works, Newcastle-on-Tyne. [*Esco, Newcastle-on-Tyne.* 432.]

1886. Silcock, Charles Whitbread, Engine Department, Medina Dock, West Cowes.

1887. Simkins, Charles Wickens, Jun., The Lodge, Lowdham, near Nottingham.

1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1889. Smith, Henry Buckley Bingham, Messrs. Sharp Stewart and Co., Atlas Works, Glasgow.

1883. Swale, Gerald, Stow Cottage, Paisley.

1887. Tabor, Edward Henry, Great Eastern Railway, Stratford Works, London, E.

1889. Tangye, Harold Lincoln, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.

1884. Taylor, Joseph, 19 Foskett Road, Fulham, London, S.W.

1884. Taylor, Maurice, Ateliers des Forges et Chantiers de la Méditerranée, Marseille, France.

1884. Templeton, Edwin Arthur Slade, 42 Boscombe Road, Shepherd's Bush, London, W.

1889. Treharne, Gwilym Alexander, Pontypridd; and Aberdare.

1889. Vesian, John Stuart Ellis de, 5 Crown Court, Cheapside, London. E.C. [*Biceps, London.*]

1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.

1888. Waddington, Samuel Sugden, Wortley Villa, Sydenham, London, S.E.

1885. Wakefield, William Marsden, care of Mark W. Carr, Government Railway, Pietermaritzburg, Natal, South Africa.

1884. Walker, Ralph Teasdale, Fabrick Olean, Sitoebondo, Java: (or Kaliemaas, Alleyne Park, West Dulwich, London, S.E.)

1888. Waring, Henry, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin; and Elsinore, Harold's Cross Road, Dublin.

1886. Warren, Frank Llewellyn, 73 Breakspears Road, St. John's, London, S.E.

1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.

1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Weymouth, Francis Marten, 33 Alfred Road, Acton, London, W.

1888. Whichello, Richard, Messrs. Max Nothmann and Co., Rio de Janeiro, Brazil: (or 44 Trumpington Street, Cambridge.)

1889. Wigham, John Cuthbert, Messrs. J. Edmundson and Co., Stafford Works, 35 Capel Street, Dublin.

1889. Willis, Edward Turnley, 99 Shooter's Hill Road, Blackheath, London, S.E.

1889. Winkfield, Richard Ernest, Locomotive Department, Great Western Railway, Swindon.

1879. Wood, Edward Walter Nealor, 7 Theresa Terrace, Hammersmith, London, W.

1885. Wray, Charles Drinkwater, care of Lieut.-General Henry Wray, 101 Comeragh Road, West Kensington, London, S.W.

1887. Wrench, John Henry Kirke, Park Lodge, Baslow, Chesterfield.

1889. Wright, Howard Theophilus, 16 Great George Street, Westminster, S.W.

1888. Yates, Edward, Watling Works, Stony Stratford.

1884. Yokoi, Saku, 110 Rue de Turenne, Paris.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

AUGUST 1878.

INTRODUCTION.

Whereas an Association (hereinafter called "the existing Institution") called "The Institution of Mechanical Engineers" has long existed for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply, and the existing Institution consists of Members, Graduates, Associates, and Honorary Life Members, and is possessed of books, drawings, and property used for the objects aforesaid;

And whereas the Institution is formed for furthering and extending the objects of the existing Institution, by a registered Association, under the Companies Acts 1862 and 1867; and terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

NOW THEREFORE IT IS HEREBY AGREED as follows:—

CONSTITUTION.

1. For the purpose of registration the number of Members of the Institution is unlimited.

MEMBERS.

2. The subscribers of the Memorandum of Association, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who, being a Member of the existing Institution, shall agree to transfer his membership of the existing Institution, and all rights and obligations incidental thereto, to the Institution, and to be registered as a Member of the Institution accordingly.

4. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, [and shall pay the entrance fee and first subscription accordingly.

5. The rights and privileges of every Member of the Institution shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

QUALIFICATION AND ELECTION OF MEMBERS.

6. The qualification of Members shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

7. The election of Members shall be conducted as prescribed by the By-laws from time to time in force, as provided by the Articles.

GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

8. Any person may become a Graduate, Associate, or Honorary Life Member of the Institution, who, being already a Graduate, Associate, or Honorary Life Member of the existing Institution, shall agree to transfer his interest in the existing Institution, and all rights and obligations incidental thereto, to the Institution.

9. The Institution may admit such other persons as may be hereafter qualified and elected in that behalf as Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the By-laws from time to time in force, as provided by the Articles: Provided that no Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

10. The qualification and mode of election of Graduates, Associates, and Honorary Life Members, shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

ENTRANCE FEES AND SUBSCRIPTIONS.

11. The Entrance Fees and Subscriptions of Members, Graduates, and Associates, shall be prescribed by the By-laws from time to time in force, as provided by the Articles: Provided that no Entrance Fee shall be payable by a Member, Graduate, or Associate of the existing Institution.

EXPULSION.

12. If any Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the list of Members, Graduates, or Associates, as the case may be, by the Council, at any time afterwards, and he shall thereupon cease to

have any rights as a Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: Provided always, that this regulation shall not be construed to compel the Council to remove any name if they shall be satisfied the same ought to be retained.

13. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the list of Members, Graduates, or Associates (as the case may be), and such person shall thereupon cease to be a Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

14. The first General Meeting shall be held on such day, within four months of the registration of the Institution, as the Council shall determine. Subsequent General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

15. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

16. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members of the Institution, specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members

of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

17. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every Member of the Institution, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

18. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the By-laws, or any regulations of the Council made in accordance with the By-laws.

PROCEEDINGS AT GENERAL MEETINGS.

19. Twenty Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purposes of a Special Meeting.

20. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

21. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if

no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

22. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded, and by a poll when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman, and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: Provided that this Article shall not interfere with the provisions of the By-laws as to election by ballot.

23. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: Provided that the Chairman may review his decision at the same Meeting if any error be then pointed out to him.

BY-LAWS.

24. The By-laws set forth in the schedule to these Articles, and such altered and additional By-laws as shall be added or substituted as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the By-laws, and all matters which consistently with the Articles shall be made the subject of By-laws. Alterations in, and additions to, the By-laws, may be made only by resolution of the Members at an Annual General Meeting, after notice of the proposed alteration or addition announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

25. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-

Presidents; and the first Council (which shall include Past-Presidents of the existing Institution) shall be as follows:—

PRESIDENT.

John Robinson	Manchester.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S.	Newcastle-on-Tyne.
Frederick J. Bramwell, F.R.S.	London.
Thomas Hawksley	London.
James Kennedy	Liverpool.
John Penn, F.R.S.	London.
John Ramsbottom	Manchester.
C. William Siemens, D.C.L., F.R.S.	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S. .	Manchester.

VICE-PRESIDENTS.

I. Lowthian Bell, M.P., F.R.S.	Northallerton.
Charles Cochrane	Stourbridge.
Edward A. Cowper	London.
Charles P. Stewart	London.
Francis W. Webb	Crewe.
Percy G. B. Westmacott.	Newcastle-on-Tyne.

COUNCIL.

Daniel Adamson	Manchester.
John Anderson, LL.D., F.R.S.E.	London.
Henry Bessemer	London.
Henry Chapman	London.
Edward Easton	London.
David Greig	Leeds.
Jeremiah Head	Middlesbrough.
Thomas R. Hetherington	Manchester.
Henry H. Laird	Birkenhead.
William Menelaus	Dowlais.
Arthur Paget	Loughborough.
John Penn, Jun.	London.
George B. Rennie	London.
William Richardson	Oldham.
John C. Wilson	Bristol.

26. The first Council shall continue in office till the Annual General Meeting in the year 1879. The President, two Vice-Presidents, and five Members of the Council (other than Past-Presidents), shall retire at each succeeding Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree amongst themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

27. The election of a President, Vice-Presidents, and Members of the Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the By-laws from time to time in force, as provided by the Articles.

28. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another, and the President or Members of the Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

29. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the By-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the By-laws the officers and servants of the Institution shall be appointed and removed by the Council.

30. The powers and duties of the officers of the Institution shall (subject to any express provision in the By-laws) be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

31. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three Members of Council shall form a quorum.

32. The Council shall acquire the property of the existing Institution, and shall manage the property, proceedings, and affairs of the Institution, in accordance with the By-laws from time to time in force.

33. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A.) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B.) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C.) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D.) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E.) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F.) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

34. The Council may, with the authority of a resolution of the Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution.

35. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members of the Institution in General Meeting, shall be afterwards impeached by any Member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

36. A notice may be served by the Council of the Institution upon any Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to such Member, Graduate, Associate, or Honorary Life Member, at his registered place of abode.

37. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

38. No Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to such Member in the same manner as if he had had due notice.

By-laws.

(Last Revision, January 1889.)

MEMBERSHIP.

1. Members, Graduates, Associates, and Honorary Life Members of the existing Institution, may, upon signing and forwarding to the Secretary of the Institution a claim according to Form D in the Appendix, become Members, Graduates, Associates, or Honorary Life Members respectively of the Institution without election or payment of entrance fees.

2. Candidates for admission as Members must be Engineers not under twenty-four years of age, who may be considered by the Council to be qualified for election.

3. Candidates for admission as Graduates must be Engineers holding subordinate situations and not under eighteen years of age; and they may afterwards be admitted as Members at the discretion of the Council.

4. Candidates for admission as Associates must be gentlemen not under twenty-four years of age, who from their scientific attainments or position in society may be considered eligible by the Council.

5. The Council shall have the power to nominate as Honorary Life Members gentlemen of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings, but Members only shall be entitled to vote thereat.

ENTRANCE FEES AND SUBSCRIPTIONS.

7. An Entrance Fee of £2 shall be paid by each Member, except Members of the existing Institution, who shall pay no Entrance Fee, and Graduates admitted as Members, who shall pay an Entrance Fee of £1. Each Member shall pay an Annual Subscription of £3.

8. An Entrance Fee of £1 shall be paid by each Graduate, except Graduates of the existing Institution, who shall pay no Entrance Fee. Each Graduate shall pay an Annual Subscription of £2.

9. An Entrance Fee of £2 shall be paid by each Associate, except Associates of the existing Institution, who shall pay no Entrance Fee. Each Associate shall pay an Annual Subscription of £3.

10. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

11. In the case of Members, Associates, or Graduates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

12. The Council may at their discretion reduce or remit the Annual Subscription, or the arrears of Annual Subscription, of any Member who shall have been a subscribing Member of the Institution for twenty years, and shall have become unable to continue the Annual Subscription provided by these By-laws.

13. No Proceedings or Ballot Lists shall be sent to Members, Associates, or Graduates, who are in arrear with their subscriptions more than twelve months, and whose subscriptions shall not have been remitted by the Council as hereinbefore provided.

ELECTION OF MEMBERS, GRADUATES, AND ASSOCIATES.

14. A recommendation for admission according to Form A in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members if the application be for admission as a Member or Associate, and by three Members if it be for a Graduate.

15. All Elections shall take place by ballot, three-fifths of the votes given being necessary for election.

16. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

17. The Elections shall take place at the General Meetings only.

18. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form B; but his name shall not be added to the list of Members, Graduates, or Associates of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form C in the Appendix.

19. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

20. A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation

according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

21. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member shall then be entitled to add to the list of Candidates. The ballot list of the proposed names shall be forwarded to the Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

22. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

23. The Secretary of the Institution shall be appointed as and when a vacancy occurs by the Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

24. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and By-laws and the directions of the President and Council; and shall refer to the President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

25. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

26. All books, drawings, communications, &c., shall be accessible to the Members of the Institution at all reasonable times.

27. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

28. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

29. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

30. The General Meetings shall be conducted as far as practicable in the following order:—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or, with the consent of the Council, by the Author.

31. Each Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member asks that this shall be done.

32. Every Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

33. The President shall ex officio be Member of all Committees of Council.

34. Seven clear days' notice at least shall be given of every meeting of the Council. Such noiice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

35. The Council shall present the yearly accounts to the Members at the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members.

36. Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

37. At any Meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being not under twenty-four years of age, and desirous of admission into the Institution of Mechanical Engineers, we the undersigned proposer and seconder from our personal knowledge, and we the three other signers from trustworthy information, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of

Members.

FORM B.

Sir,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. In conformity with the rules, your election cannot be confirmed until the enclosed form be returned to me with your signature, and until your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM C.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM D.

As a of the Institution of Mechanical Engineers, I claim to become a of the Association incorporated under the same name.

Please register me as a

FORM E.

Mr. being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become a Member of the Institution of Mechanical Engineers.

FORM F.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM G.

Sir,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

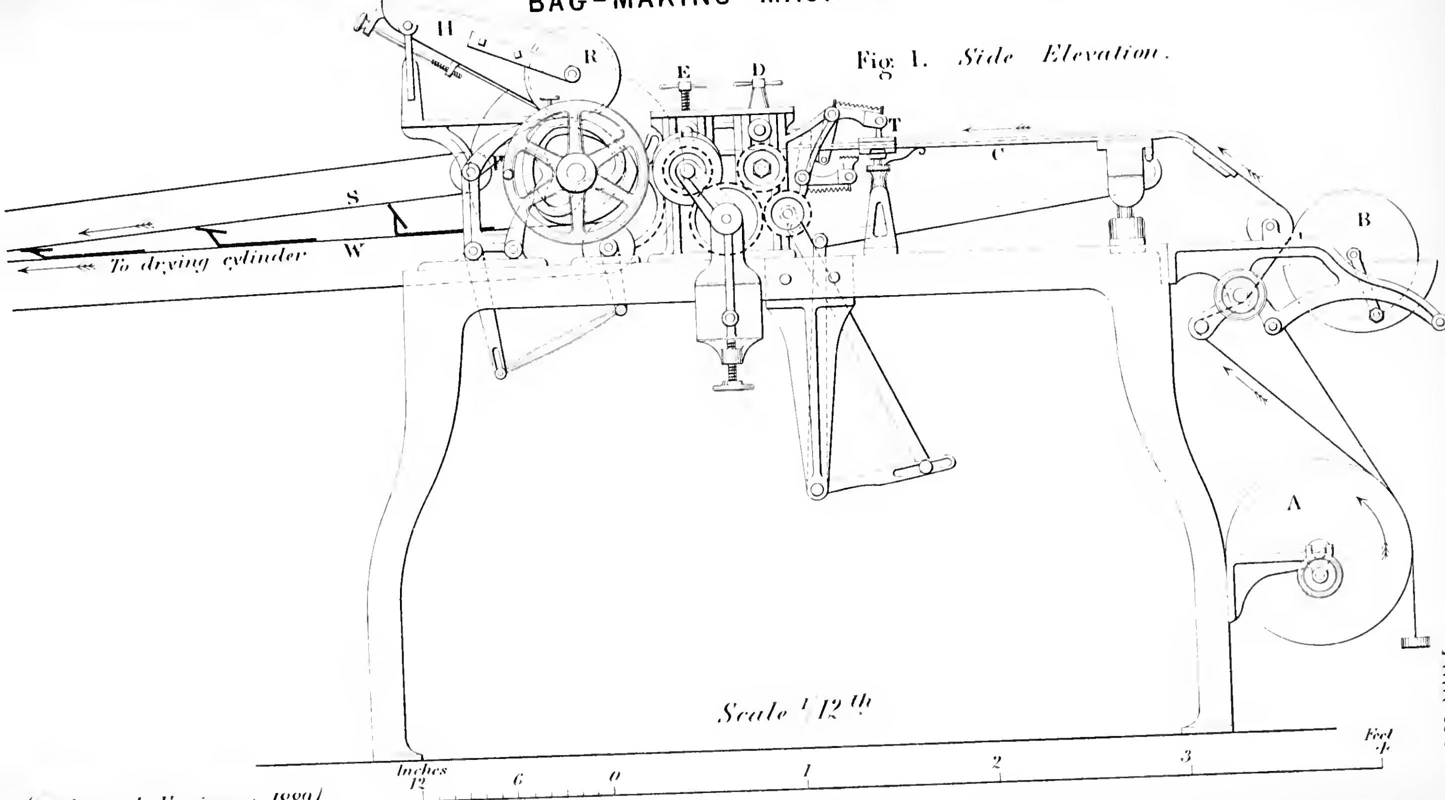
FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

BAG-MAKING MACHINE.

Fig. 1. *Side Elevation.*



BAG-MAKING MACHINE.

Fig. 2. *Plan.*

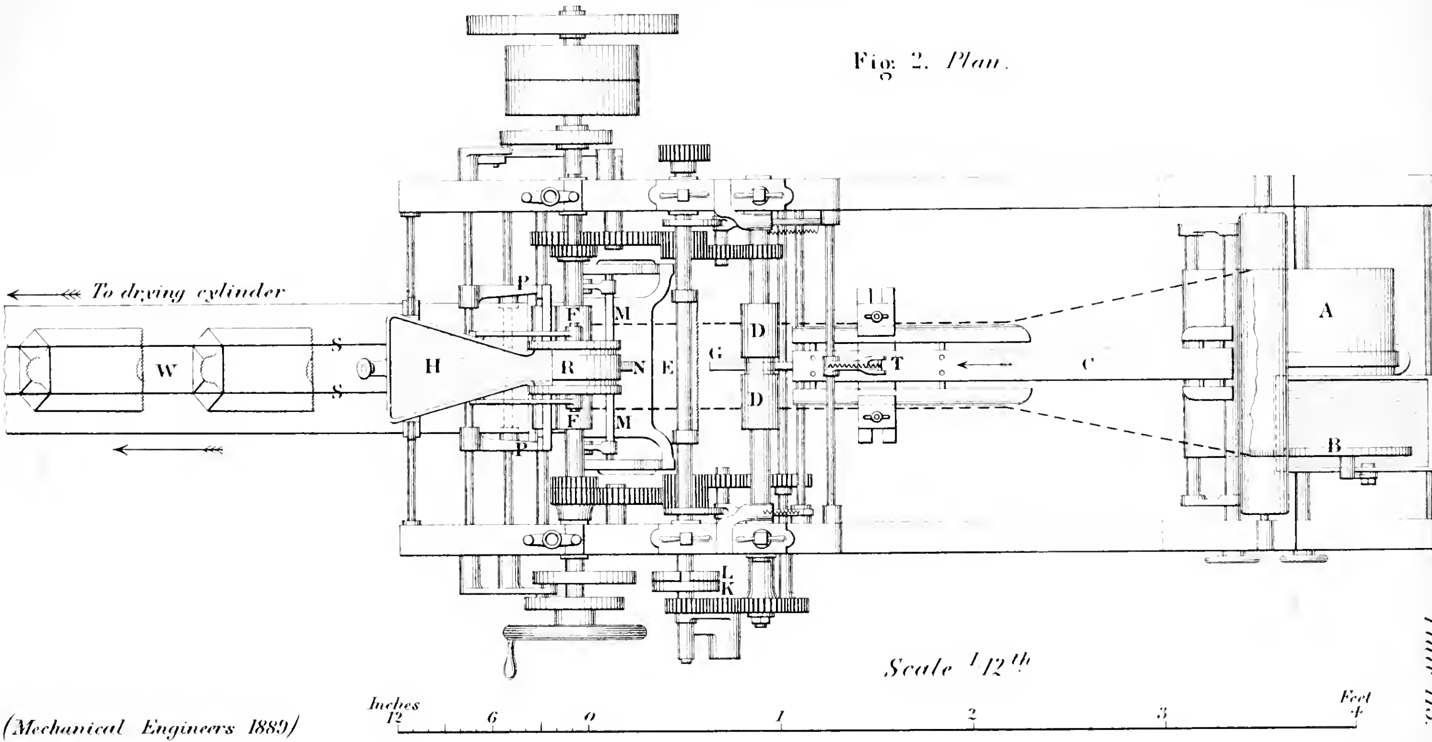


Plate 115.

BAG-MAKING MACHINE.

Fig. 3.

Longitudinal Section.

Scale 1/4th

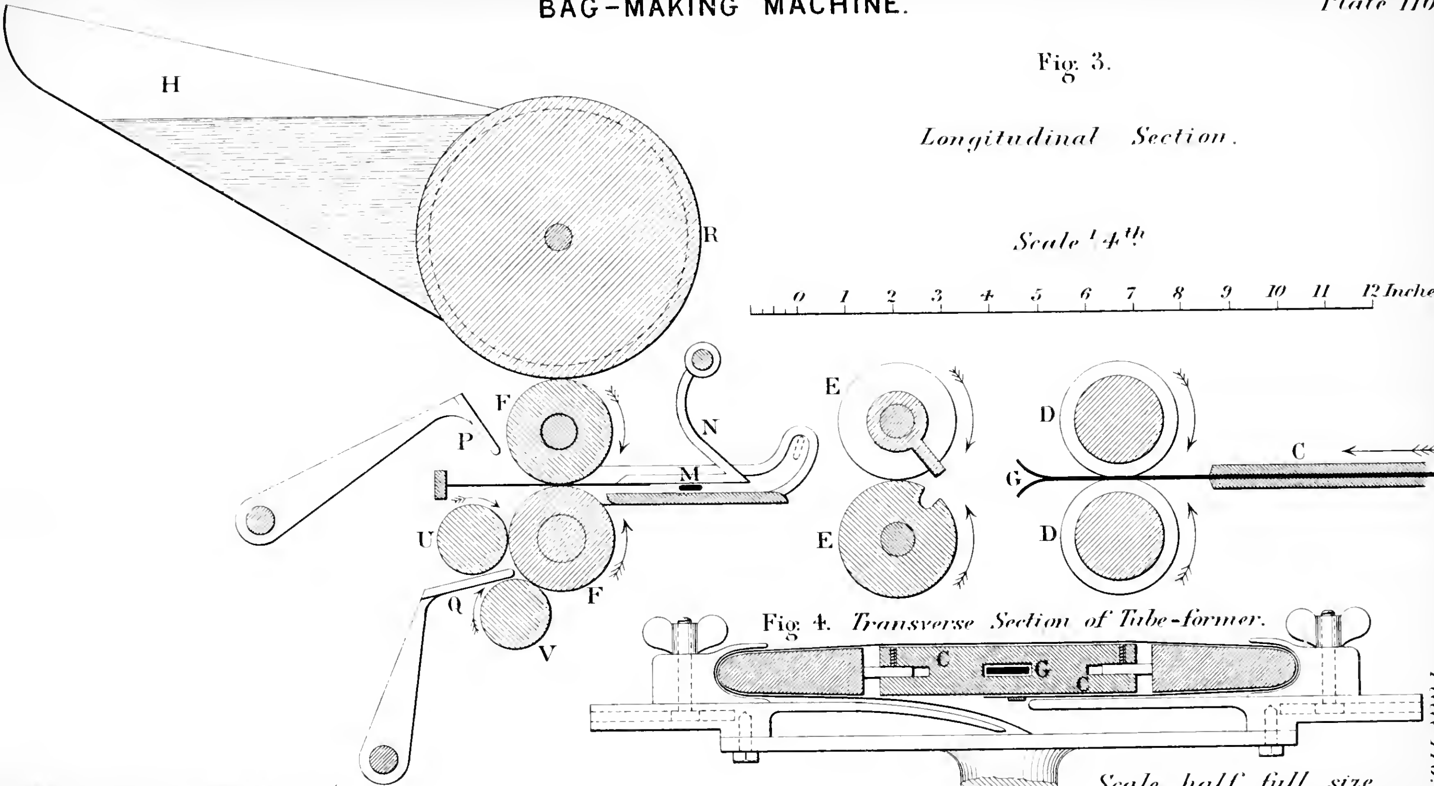


Fig. 4. Transverse Section of Tube-former.

Scale half full size

(Mechanical Engineers 1889)

Plate 116.

BAG-MAKING MACHINE.

Fig. 9. Completed bag.

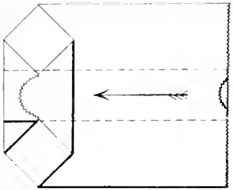


Fig. 8. Blind fold and second bottom fold.

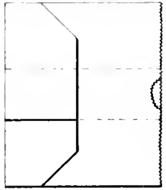


Fig. 7. First bottom fold.

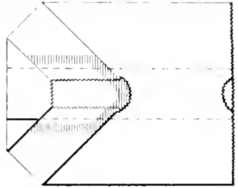
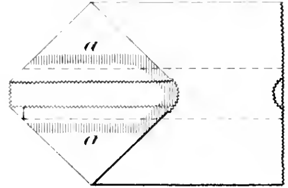


Fig. 6. Diamond fold.



Scale 1/6th

Fig. 5. Bag-length of paper tube.

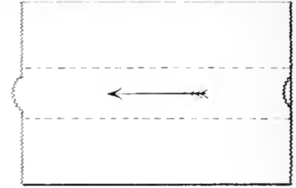
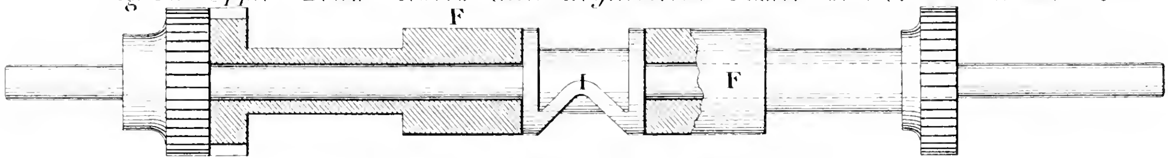


Fig. 10. Upper Draw-Rolls and Segmental Paster-block. Scale 1/4th



Variable motion for Severing Rolls.

Scale 1/4th

Fig. 11.

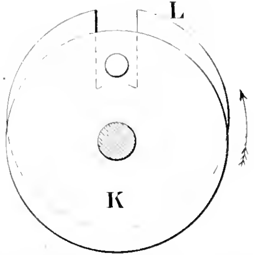


Fig. 12.

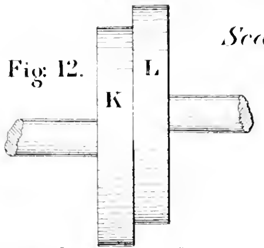


Fig. 13.

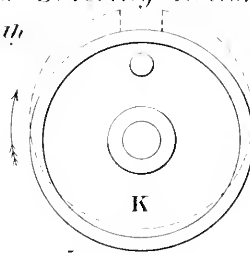
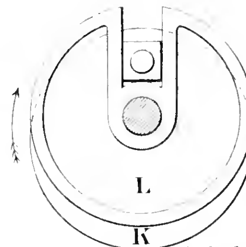


Fig. 14.



0 5 10 15 Inches

(Mechanical Engineers 1889) Scale 1/4th

Plate 117.

BAG-MAKING MACHINE.

Conveyance of Bags to Drying Cylinder, and Opening-out of blind fold.

Fig: 15. *Plan.*

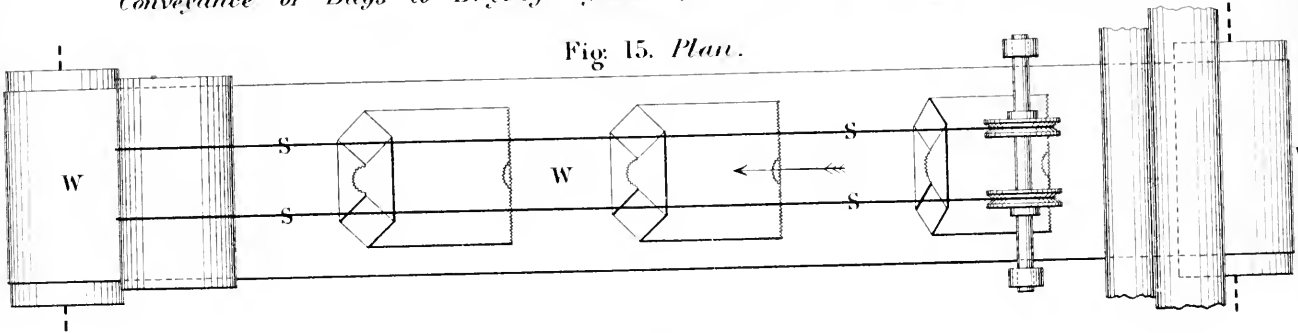


Fig: 16. *Side Elevation.*

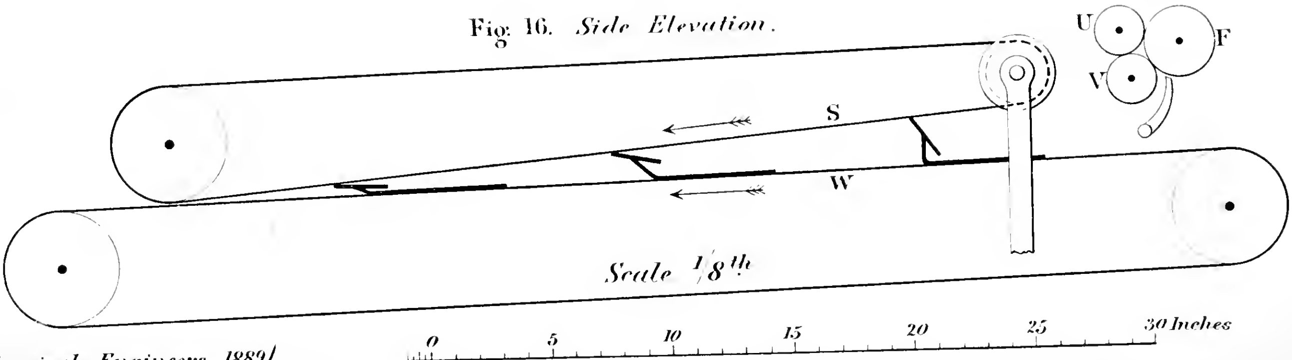


Plate 118.

CONDENSATION AND RE-EVAPORATION.

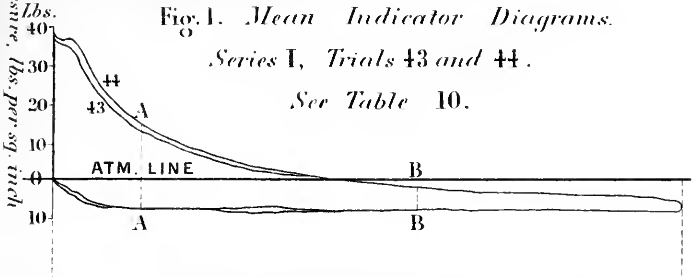


Fig. 1. Mean Indicator Diagrams.
Series I, Trials 43 and 44.
See Table 10.

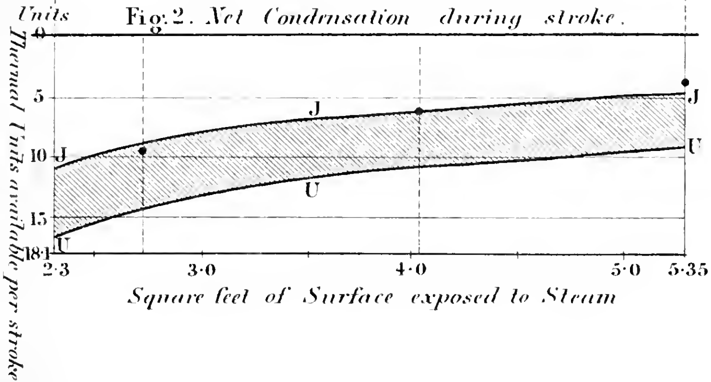


Fig. 2. Net Condensation during stroke.

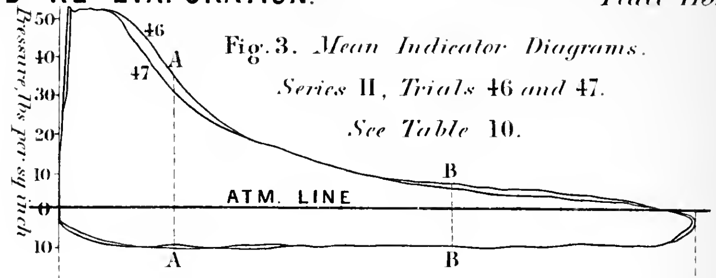


Fig. 3. Mean Indicator Diagrams.
Series II, Trials 46 and 47.
See Table 10.

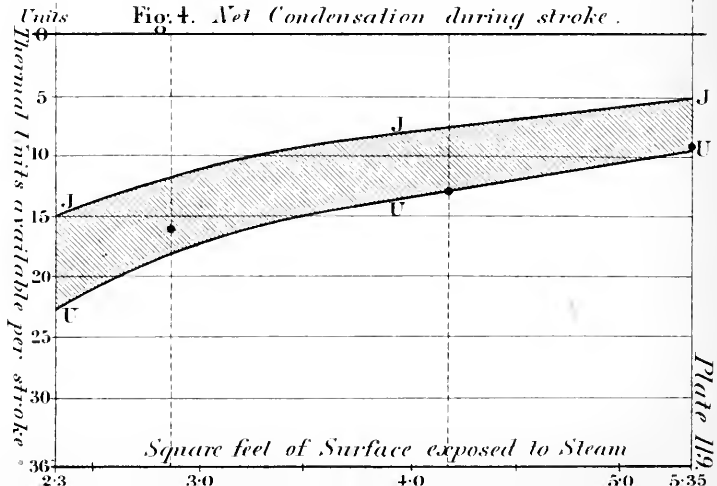


Fig. 4. Net Condensation during stroke.

Plate 119.

CONDENSATION AND RE-EVAPORATION.

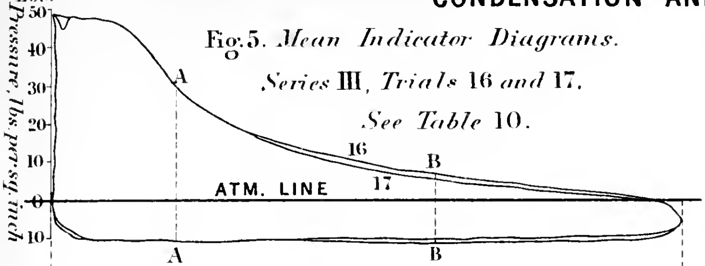


Fig. 5. *Mean Indicator Diagrams.*
Series III, *Trials* 16 *and* 17.
See Table 10.

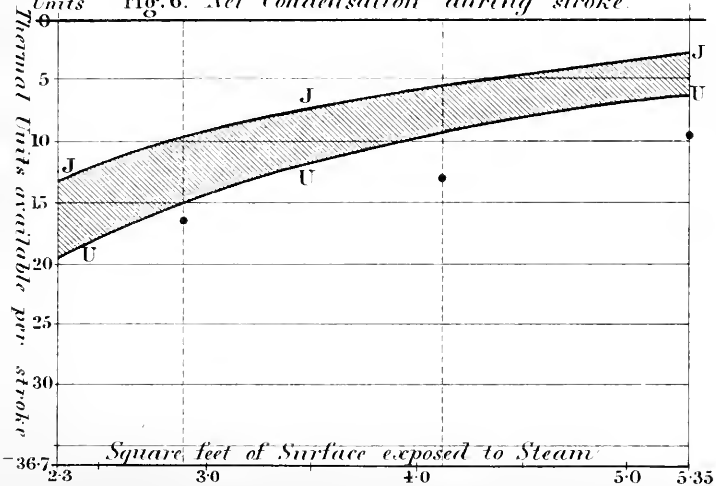


Fig. 6. *Net Condensation during stroke.*

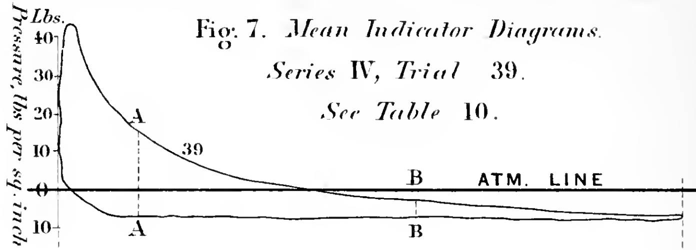


Fig. 7. *Mean Indicator Diagrams.*
Series IV, *Trial* 39.
See Table 10.

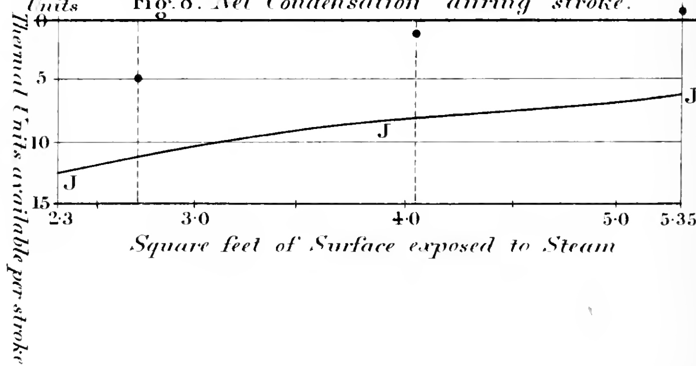
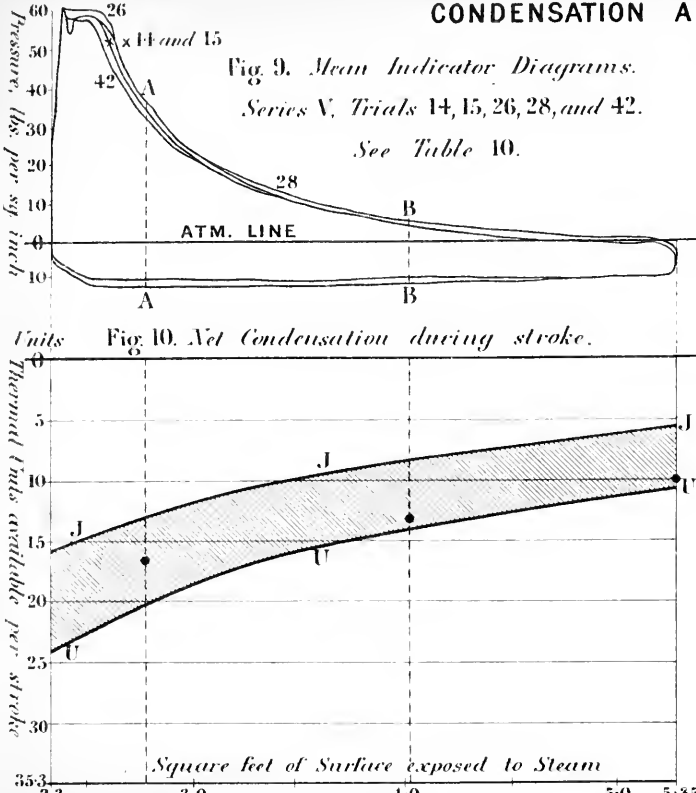
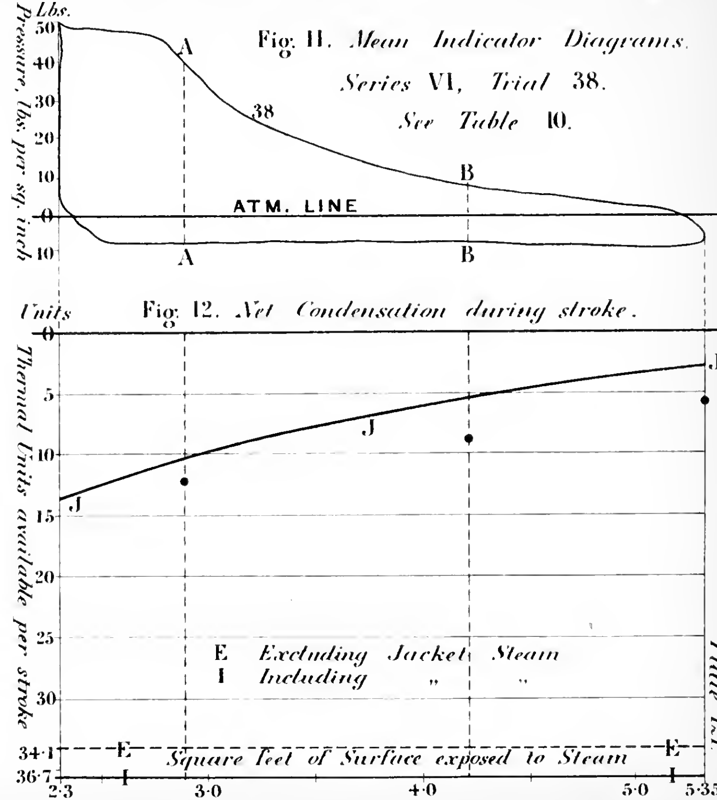


Fig. 8. *Net Condensation during stroke.*

CONDENSATION AND RE-EVAPORATION.





(Mechanical Engineers 1889)

Plate 121.

CONDENSATION AND RE-EVAPORATION.

Fig. 13. *Mean Indicator Diagrams.*
Series VII, *Trials* 52, 53, *and* 54.
See Table 10.

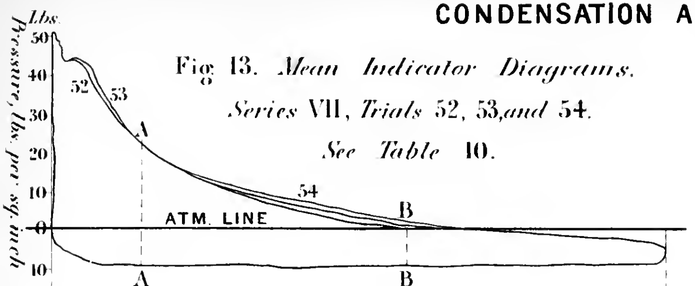


Fig. 14. *Net Condensation during stroke.*

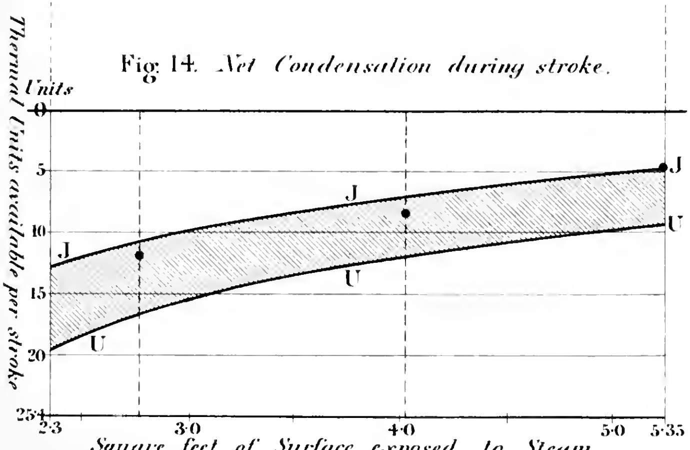


Fig. 15. *Mean Indicator Diagrams.*
Series VIII, *Trials* 45 *and* 55.
See Table 10.

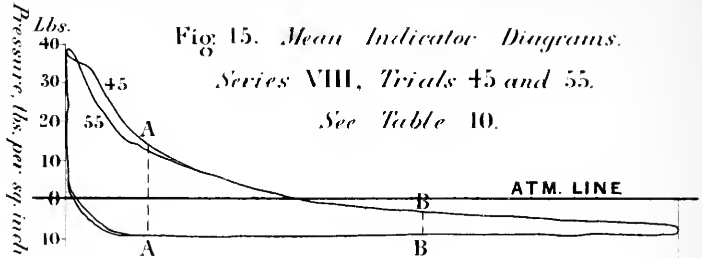
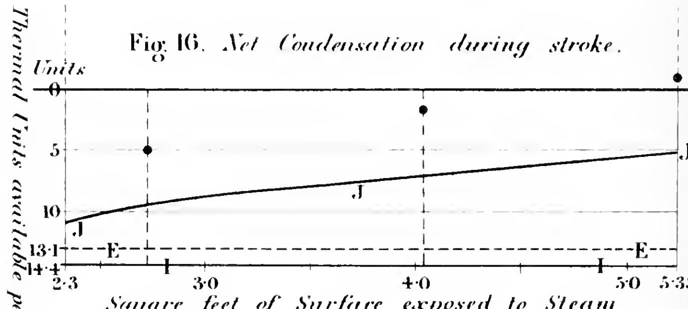


Fig. 16. *Net Condensation during stroke.*



E *Excluding Jacket Steam*
I *Including* " "

(Mechanical Engineers 1889)

CONDENSATION AND RE-EVAPORATION.

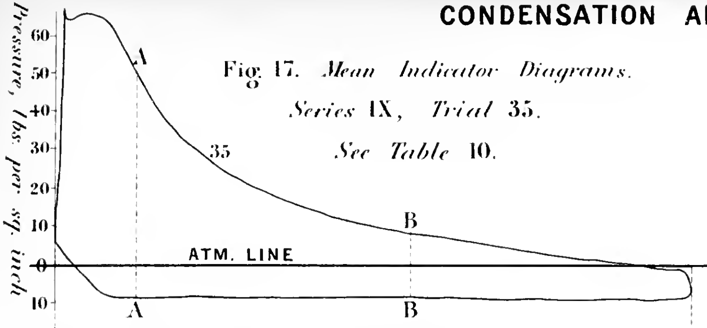


Fig. 17. Mean Indicator Diagrams.
Series IX, Trial 35.
See Table 10.

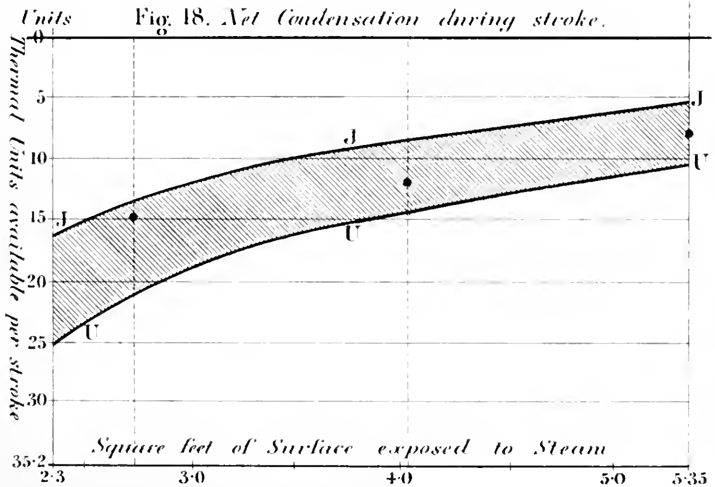


Fig. 18. Net Condensation during stroke.

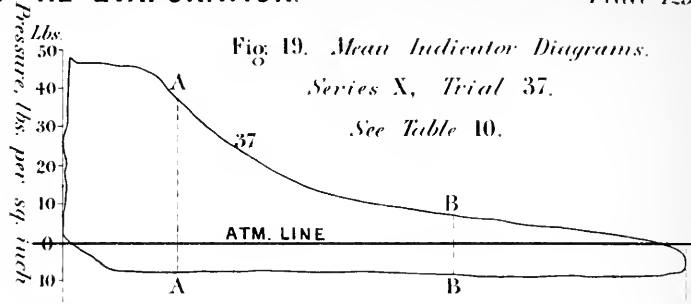


Fig. 19. Mean Indicator Diagrams.
Series X, Trial 37.
See Table 10.

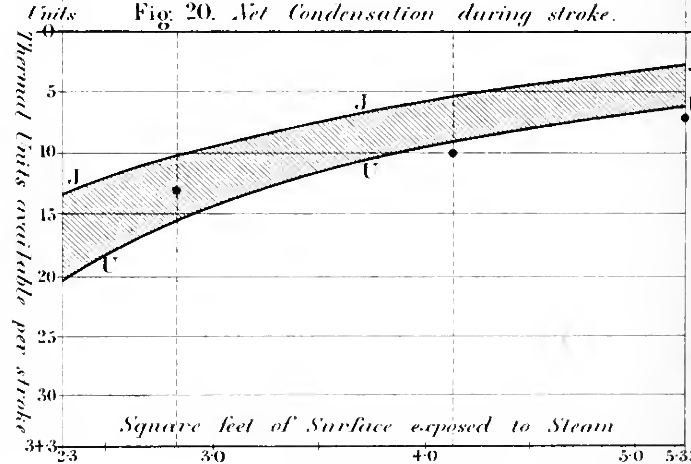


Fig. 20. Net Condensation during stroke.

(Mechanical Engineers 1889)

CONDENSATION AND RE-EVAPORATION.

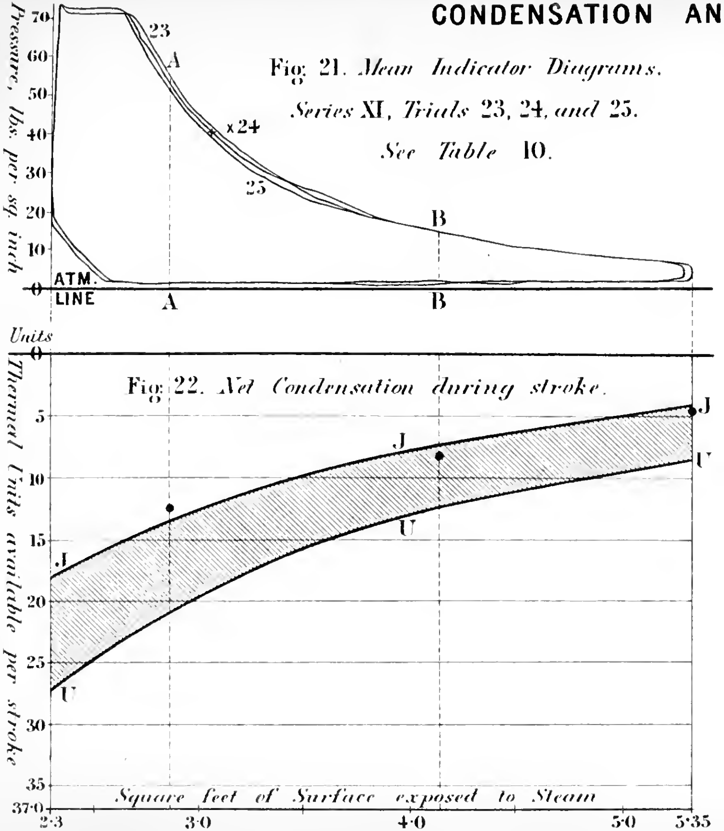


Fig. 21. *Mean Indicator Diagrams.*
Series XI, *Trials* 23, 24, *and* 25.
See Table 10.

Fig. 22. *Net Condensation during stroke.*

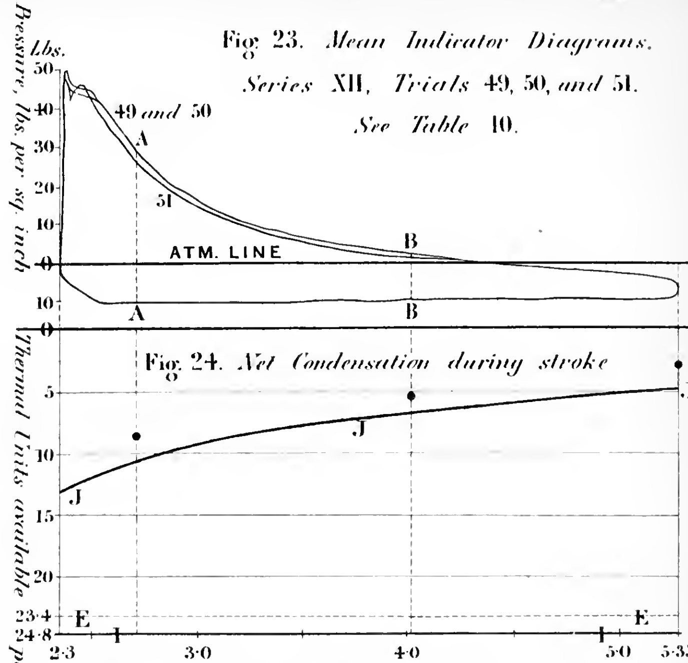


Fig. 23. *Mean Indicator Diagrams.*
Series XII, *Trials* 49, 50, *and* 51.
See Table 10.

Fig. 24. *Net Condensation during stroke*

E *Excluding Jacket Steam*
I *Including " "*
(Mechanical Engineers 1889)

Plate 124.

CONDENSATION AND RE-EVAPORATION.

Fig. 25. *Mean Indicator Diagrams.* *Series* XIII, *Trial* 48. *See Table* 10.

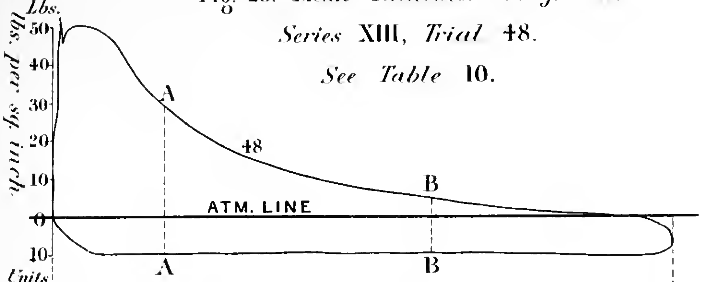
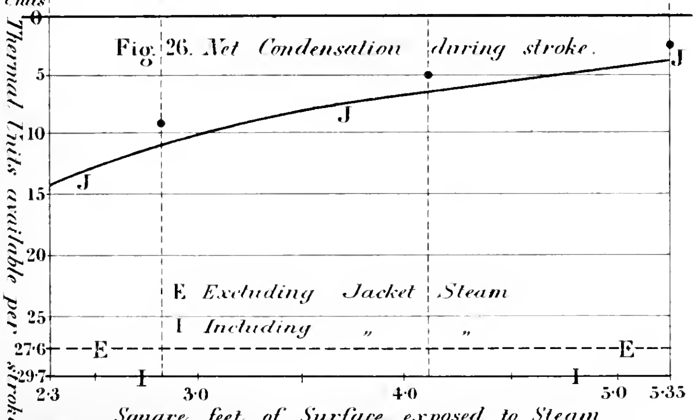


Fig. 26. *Net Condensation during stroke.*



(Mechanical Engineers 1889)

Fig. 27. *Mean Indicator Diagrams.* *Series* XIV, *Trials* 18, 21, *and* 22. *See Table* 10.

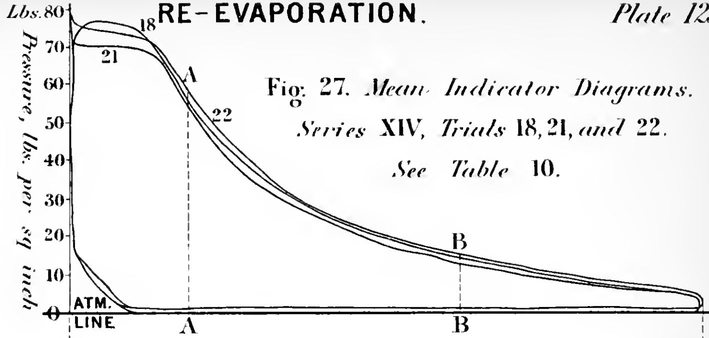


Fig. 28. *Net Condensation during stroke.*

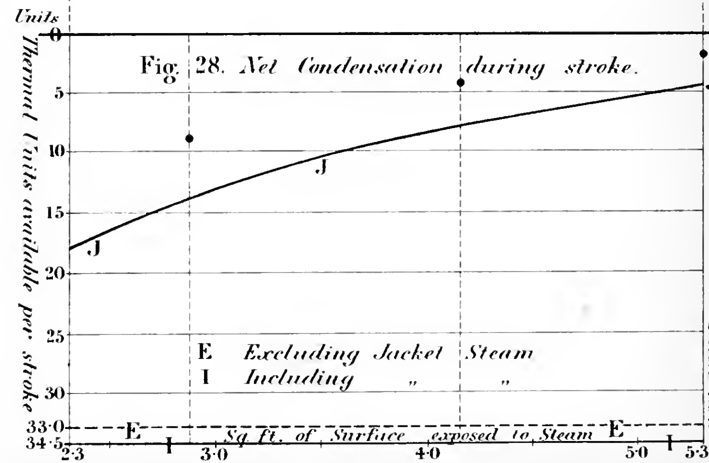


Plate 125.

CONDENSATION AND RE-EVAPORATION.

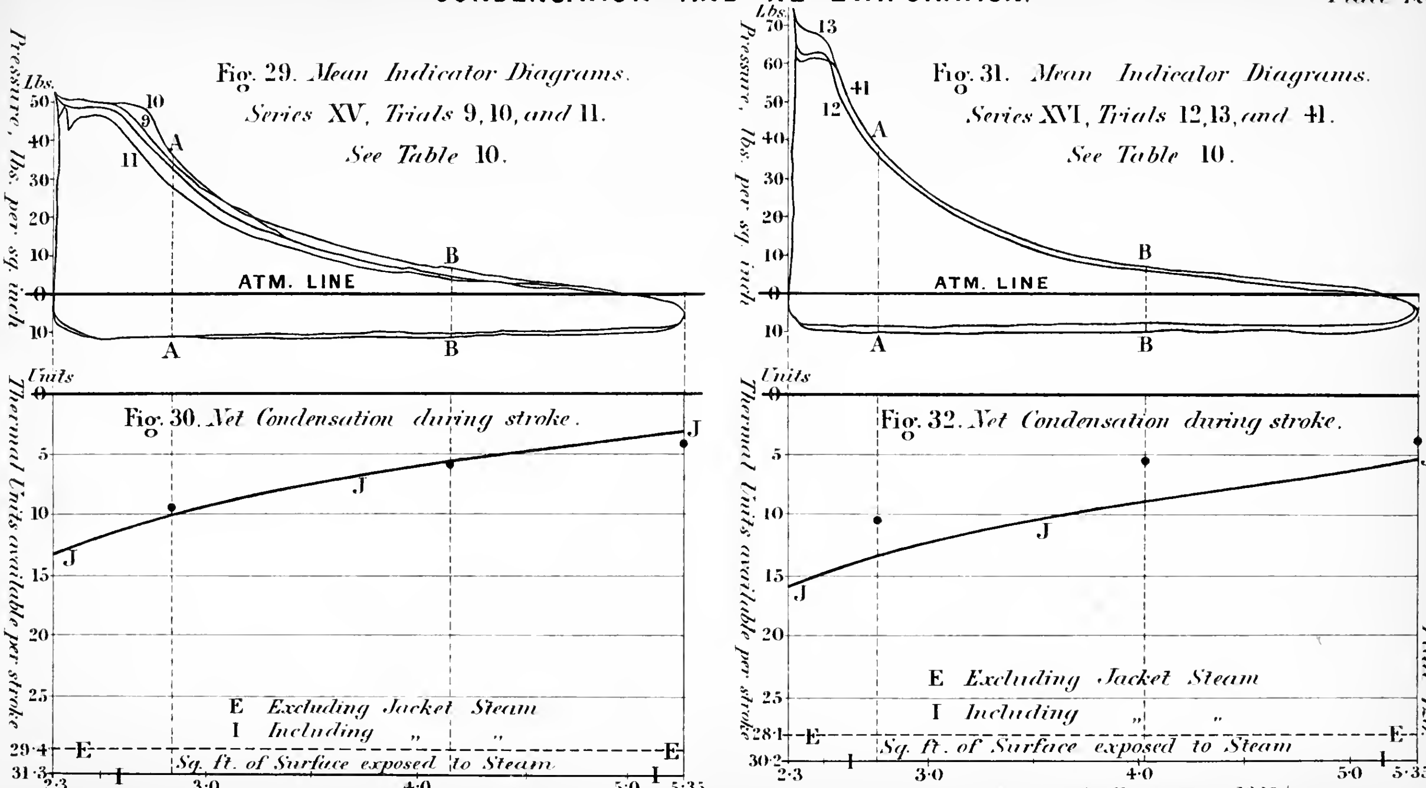


Fig. 29. *Mean Indicator Diagrams. Series XV, Trials 9, 10, and 11. See Table 10.*

Fig. 30. *Net Condensation during stroke.*

Fig. 31. *Mean Indicator Diagrams. Series XVI, Trials 12, 13, and 41. See Table 10.*

Fig. 32. *Net Condensation during stroke.*

(Mechanical Engineers 1889)

Plate 126.

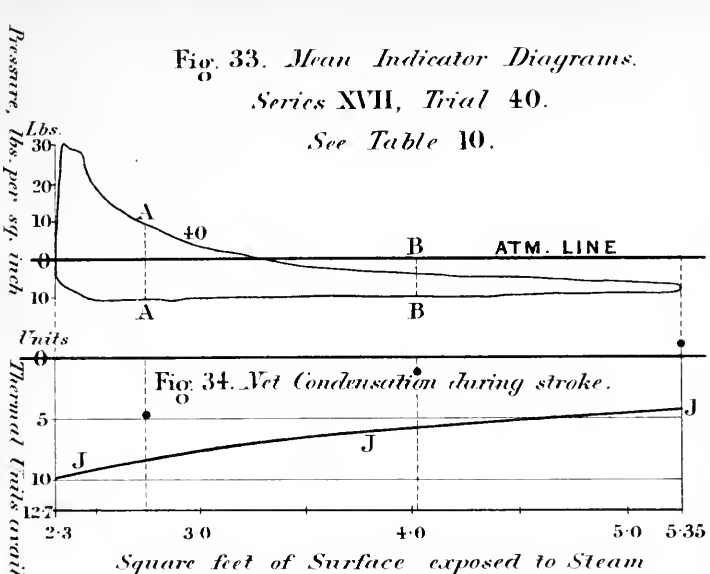


Fig. 33. *Mean Indicator Diagrams.*
Series XVII, *Trial* 40.
See Table 10.

Fig. 34. *Net Condensation during stroke.*

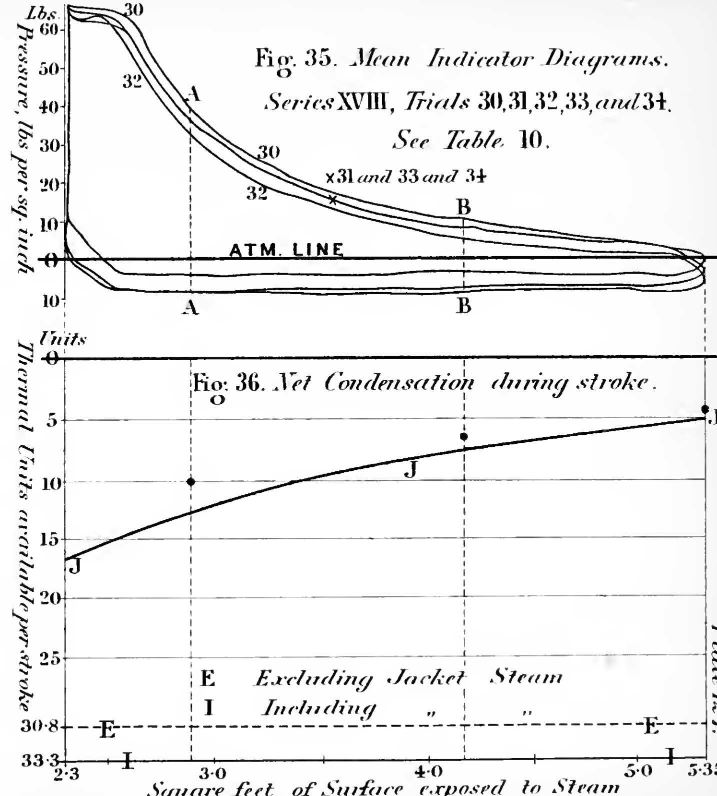


Fig. 35. *Mean Indicator Diagrams.*
Series XVIII, *Trials* 30, 31, 32, 33, *and* 34.
See Table 10.

Fig. 36. *Net Condensation during stroke.*

Water used in Cylinder per stroke.

• • • • *Observed results.* *See Table* 10.

UJ —— *Calculated results: U as Unjacketed; J as Jacketed.*

W- - - - - *Accounted for by indicator at cut-off.*

Fig. 37. *Jacket drain-cock shut.*

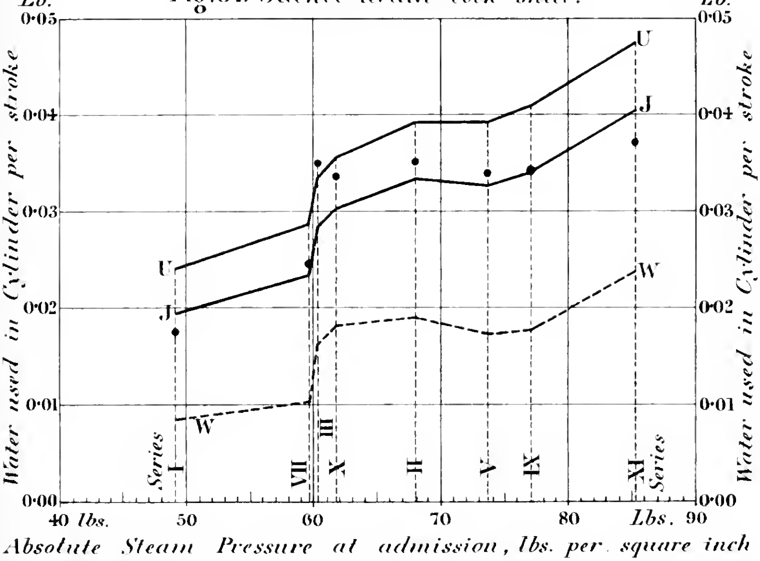
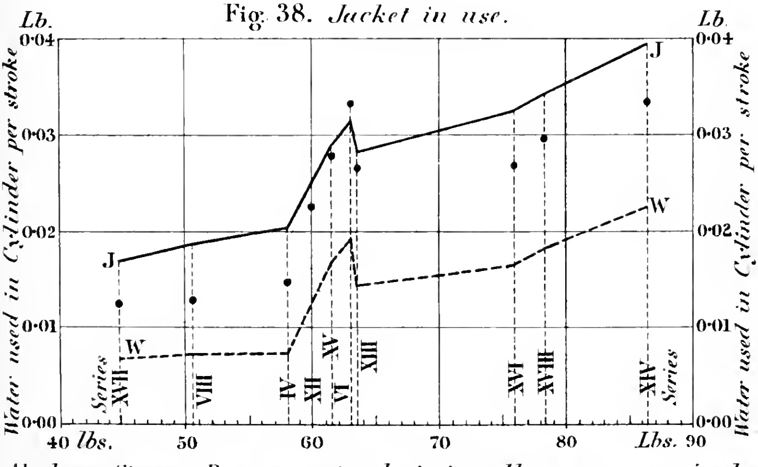


Fig. 38. *Jacket in use.*



(Mechanical Engineers 1889)

Comparison of Mr. Willans' Observed results with Calculation.
Non-Condensing Simple Engine. *See Table* 12.

• • • • • *Observed results.*
FC ——— *Calculated results.*
W - - - - - *Accounted for by indicator at cut-off.*

Fig. 39. *Mr. Willans' Table* V.

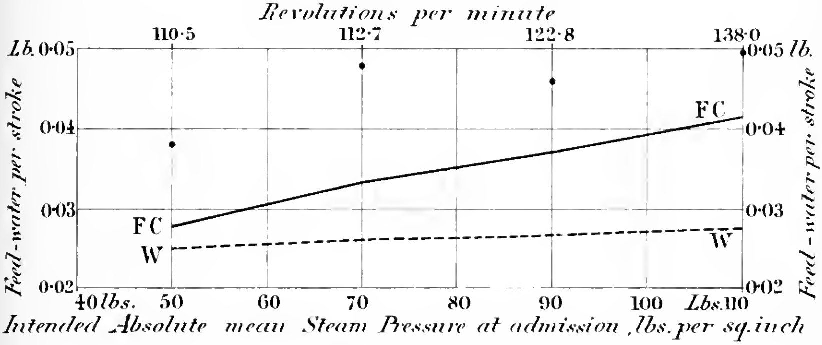


Fig. 40. *Mr. Willans' Table* V.

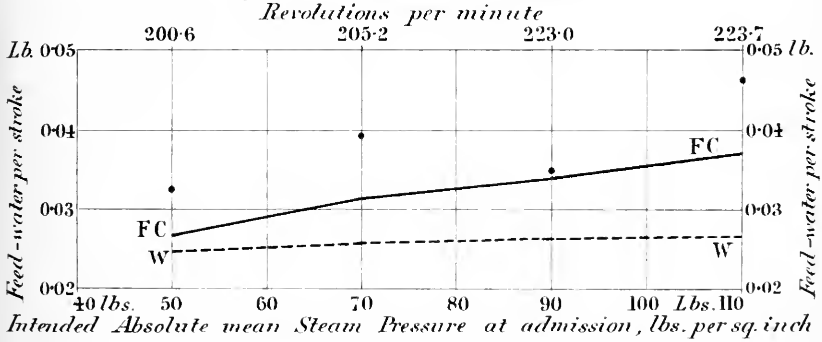
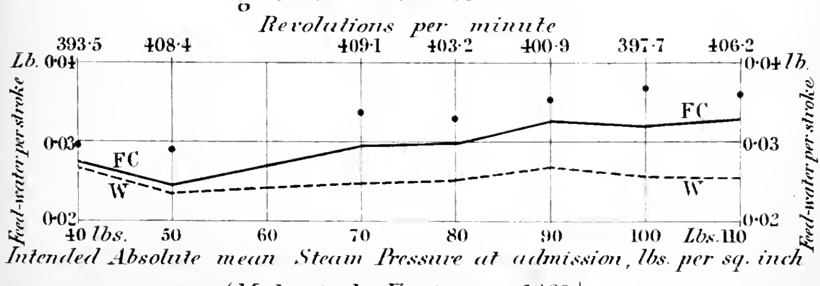


Fig. 41. *Mr. Willans' Table* 1.



(Mechanical Engineers 1889)

Comparison of Mr. Willans' Observed results with Calculation.
Non-Condensing Compound Engine. *See Table 12.*
• • • • *Observed results.* FC —— *Calculated results.*
W - - - - *Accounted for by indicator at cut-off.*

Fig. 42. *Mr. Willans' Table VII.*

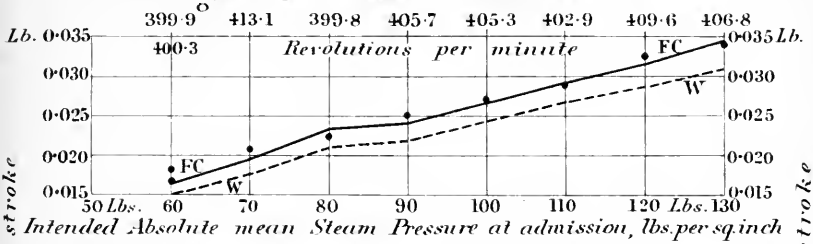


Fig. 43. *Mr. Willans' Table II. Ratio of Expansion* $= \frac{P}{25}$

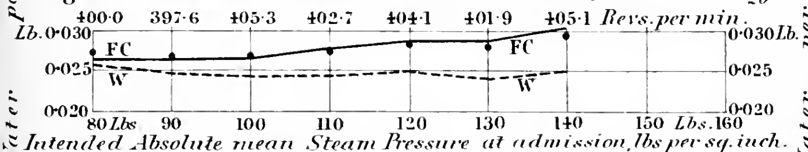


Fig. 44. *Mr. Willans' Table II. Ratio of Expansion* $= \frac{P-10}{25}$

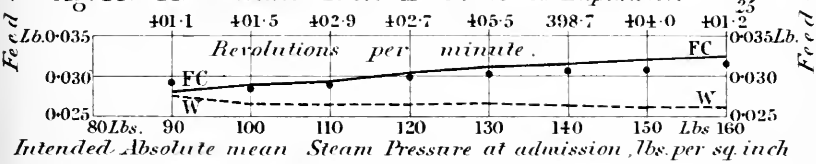


Fig. 45. *Mr. Willans' Table VI.*

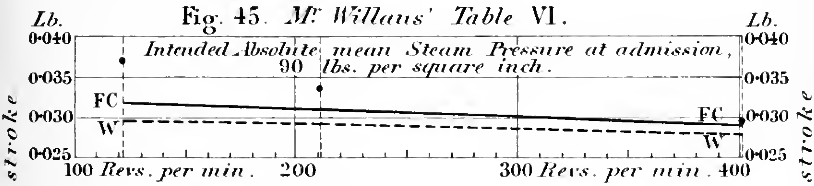


Fig. 46. *Mr. Willans' Table VI.*

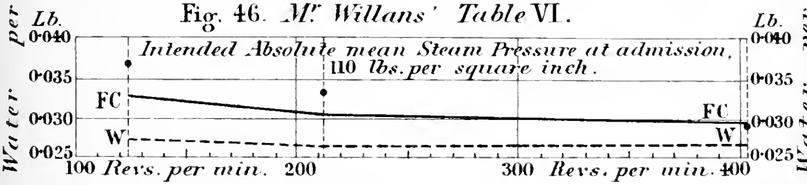
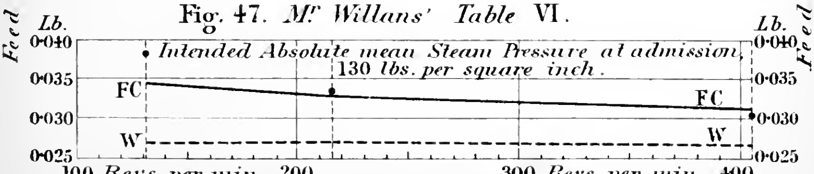


Fig. 47. *Mr. Willans' Table VI.*



Comparison of Mr. Willans' Observed results with Calculation.
Non-Condensing Compound and Triple Engine. *See Table 12.*
• • • • *Observed results.* FC ——— *Calculated results.*
W - - - - - *Accounted for by indicator at cut-off.*

Fig. 48. *Compound Engine. Mr. Willans' Table* IV.

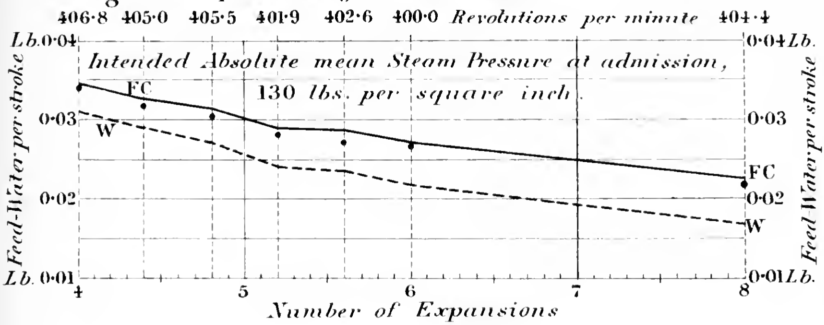


Fig. 49. *Compound Engine. Mr. Willans' Table* VIII.

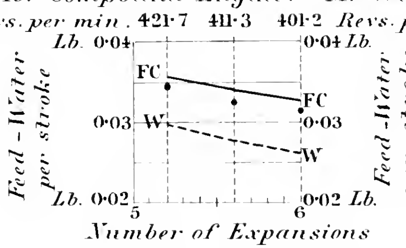
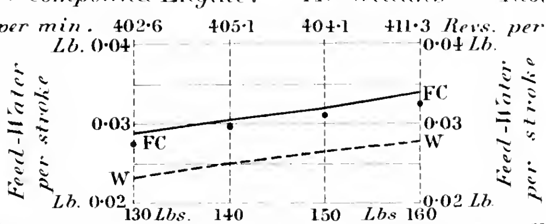
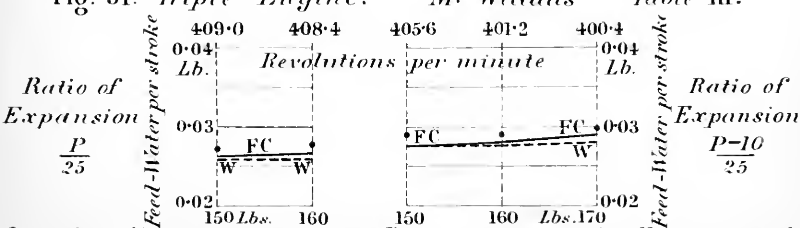


Fig. 50. *Compound Engine. Mr. Willans' Table* IX.



Intended Absolute mean Steam Pressure at admission, lbs. per sq. inch

Fig. 51. *Triple Engine. Mr. Willans' Table* III.



Intended Absolute mean Steam Pressure at admission, lbs. per sq. inch
(Mechanical Engineers 1889)

Density of Steam and Initial Condensation.

Fig: 52. *Varying Density of Steam. Constant Cut-off.*

● ● ● ● *Observed results.* ○ ○ ○ ○ *Calculated results.*

See M^r^ *Willans' Table* VII *under Table 12.*

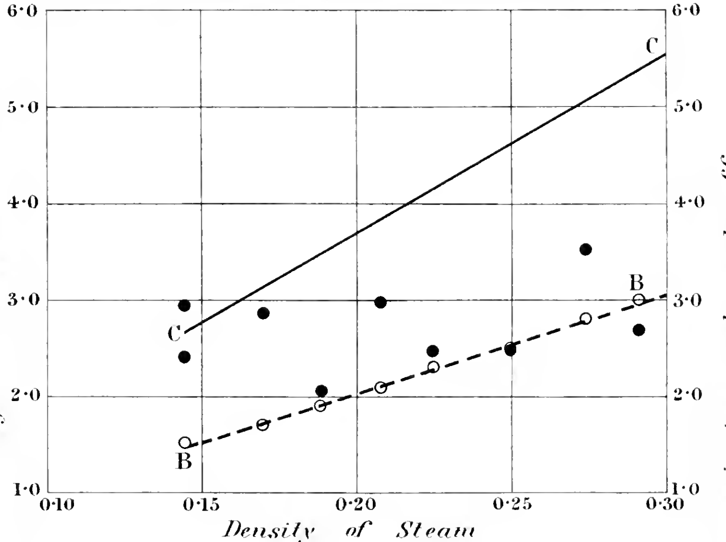
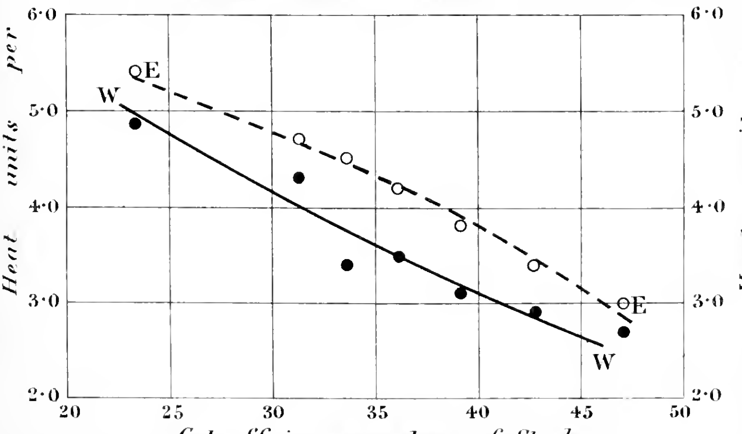


Fig: 53. *Constant Density of Steam. Varying Cut-off.*

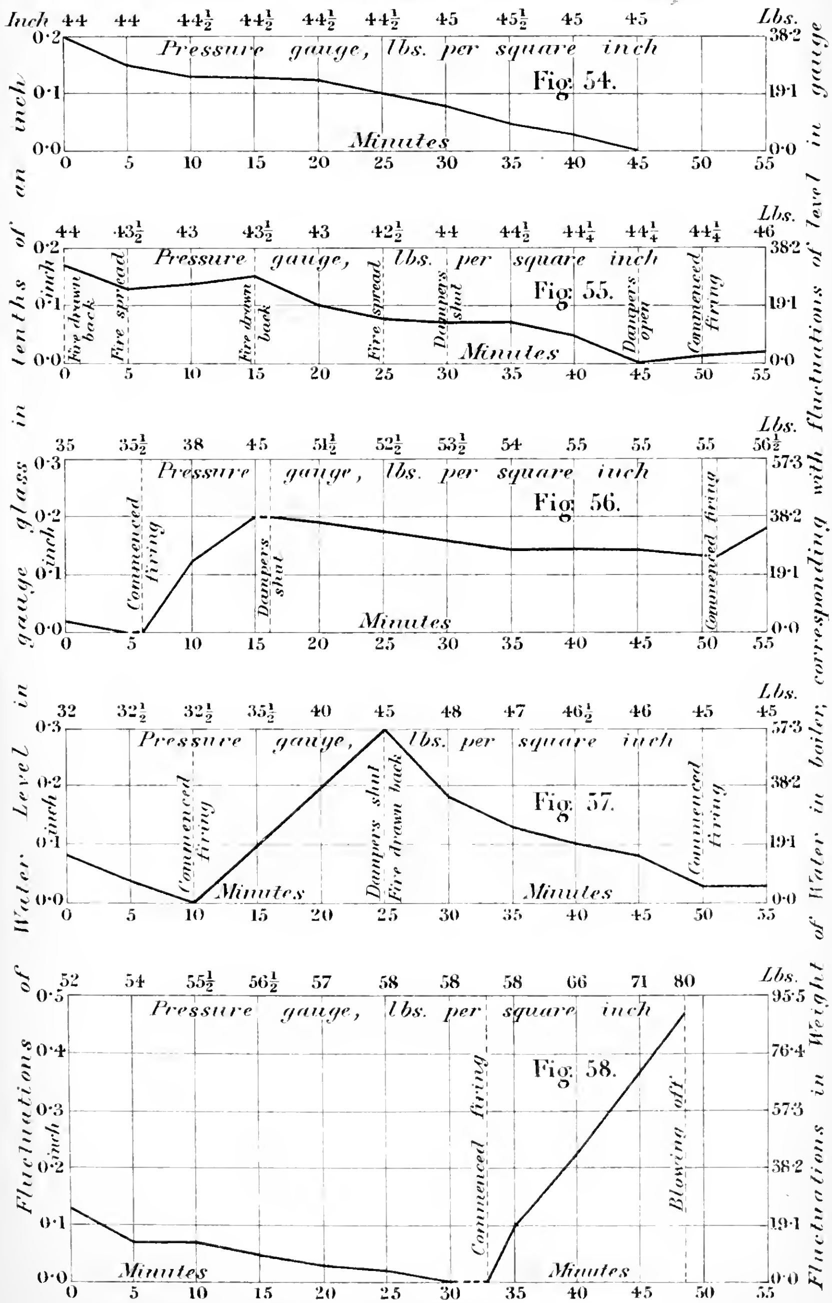
● ● ● ● *Observed results.* ○ ○ ○ ○ *Calculated results.*

See M^r^ *Willans' Table* IV *under Table 12.*



(Mechanical Engineers 1889)

Variations in Internal Capacity of Boiler according to varying action of furnace.



(Mechanical Engineers 1889)

1.35

Institution of Mechanical Engineers.

PROCEEDINGS.

January 1889.

The Forty-Second Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 30th January 1889, at Half-past Seven o'clock p.m.; Edward H. Carbutt, Esq., Retiring President, in the chair, succeeded by Charles Cochrane, Esq., President elected at the Meeting.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-two candidates were found to be duly elected:—

MEMBERS.

Samuel Gordon Breebner,	Poona.
Francis Clarke,	Canterbury.
Wolf Defries,	London.
Harry Etches,	Eastbourne.
Henry Bedwell Fisher,	Brighton.
James Walter Grimshaw,	Sydney.
Alfred Farquharson Hoggins,	Birmingham.
James Knox,	Auckland, N.Z.
Arthur John Lucy,	Calcutta.
Robert Lundon,	Melbourne.
George Macallan,	London.
Adam Miller,	London.
Joseph Edward Needham,	London.

FRED OGDEN, ...	London.
ALAN WOOD RENDELL, . . .	Kanchrapara.
JOSEPH RICHMOND, ...	London.
ALFRED TOWLER, ...	Leeds.
JOSEPH JOHN TYRRELL, . . .	Lincoln.

ASSOCIATE.

FREDERICK WILLIAM GOLBY, . .	London.

GRADUATES.

FREDERICK ALEXANDER WILLIAM BROWN,	Woolwich.
WILLIAM ERNEST HAMPTON, . . .	Woolwich.
WALTER ROOPE, ...	London.

The election of Mr. John Darbyshire, of Bradford, whose name had been included in the Ballot List, was unfortunately rendered void by his subsequent decease.

The following Annual Report of the Council was then read :—

ANNUAL REPORT OF THE COUNCIL.

1889.

The Annual Report which the Council have now the pleasure of presenting to the Members marks the completion of the forty-second year since the establishment of this Institution in 1847. At the end of last year the number of names of all classes on the roll of the Institution was 1806, as compared with 1741 at the end of the previous year, showing a net gain of 65. During 1888 there were added to the register 143 names; against which the loss by deceases was 17, and by resignation or removal 61.

The following transferences of Graduates to the class of Members have been made by the Council in 1888:—

JOHN HERBERT HOLROYD,	India.
THOMAS EGERTON KEYWORTH,	Argentine Republic.
CHARLES HERBERT SCOTT,	Sheffield.
MATTHEW WALKER,	Nottingham.
ROBERT JOHN WALKER,	Shap.

The following twenty-five Deceases of Members of the Institution have occurred during the past year:—

JOSEPH ARMSTRONG (Graduate),	Wolverhampton.
WILLIAM BAWDEN,	Manchester.
WILLIAM CLARK,	Mansfield.
FRANCIS CHRISTOPHER COCKEY,	Frome.
THOMAS RUSSELL CRAMPTON,	London.
GEORGE DAVIDSON,	Sydney.
WILLIAM ALFRED HARRY DE PAPE,	Tottenham.
JAMES J. A. FLOWER,	London.
OTTO GÖSSELL (Associate),	London.
ROBERT HADFIELD,	Sheffield.
THOMAS ELLIOT HARRISON,	Newcastle-on-Tyne.
CHARLES MARKHAM,	Chesterfield.
STURGES MEEK,	Manchester.
WILLIAM MUIR,	London.
ALBERT LEWIS NEWDIGATE,	Dover.

RALPH PEACOCK (deceased 1887), ...	Goole.
JOSIAH RICHARDS, ...	Pontypool.
HENRY ROBERTSON, ...	Corwen.
The Hon. WILLIAM RUSSELL, ...	Demerara.
FRANK SALTER, ...	London.
CHARLES HENRY TURNBULL, ...	Liverpool.
JOHN WADDELL, ...	Edinburgh.
CHARLES WETHERELL WARDLE, ...	Leeds.
PATRICK LAMBERT WEATHERHEAD, ...	Seville.
BENJAMIN FREDERICK WRIGHT, ...	Japan.

Of these Mr. Crampton had been a Member of the Institution from the year of its commencement, a Member of Council from 1879 to 1882, and a Vice-President in 1883.

The annual death-rate per thousand in the roll of the Institution during the past thirty-one years has been as follows, the highest rate having been 21·16 in 1874 and the lowest 4·60 in 1865, while the mean for the whole period is 12·32 per thousand per annum :—

1857	9·97	1865	4·60	1873	15·69	1881	14·89
1858	14·66	1866	5·49	1874	21·16	1882	16·79
1859	15·35	1867	10·11	1875	13·75	1883	16·67
1860	16·36	1868	7·27	1876	13·45	1884	12·87
1861	12·93	1869	8·18	1877	12·09	1885	10·98
1862	6·04	1870	11·60	1878	14·91	1886	13·14
1863	14·81	1871	17·14	1879	6·79	1887	9·76
1864	17·48	1872	8·77	1880	8·26	Mean	**12·32**

The following twenty-two gentlemen have ceased to be Members of the Institution during the past year :—

JOHN BAILEY, ...	Boulogne-sur-mer.
EDWIN PHILP BASTIN, ...	Uxbridge.
ALFRED LUTHER BEATTIE, ...	Dunedin, N.Z.
DAVID STANLEY BEESLEY (Graduate), . . .	Birmingham.
FREDERICK AUGUSTUS BRADLEY, ...	Eldorado, U.S.
GERALD VAUGHAN BURROWES (Graduate), . .	Golahghaut, India.
JOHN WILFRID DE VILLEMONT GALWEY, . .	Warrington.
HENRY JOHN CUBITT KEYMER, ...	Great Yarmouth.
ARCHIBALD ROBERT MACKINTOSH, ...	Melbourne.
GEORGE BENJAMIN MALLORY, ...	New York.

WILLIAM MELLAND MANLOVE, ...	Chesterfield.
BENJAMIN MCKAY, ...	Mackay, Queensland.
WILLIAM MALLABEY MURDOCK, ...	Gilwern.
ROBERT ROBSON NEWLOVE, ...	Nottingham.
FREDERIC WILLIAM NORTH, ...	Dudley.
JOHN SINCLAIR PIRRIE, ...	Croydon.
EDWARD SNOWBALL, ...	New Plymouth, N.Z.
MAJOR-GENERAL ALEXANDER SOKOLOFF, . .	Cronstadt.
GEORGE HENRY SOLLORY (Graduate), . . .	Nottingham.
BROOKE MIDDLEMORE WHITHARD, . . .	London.
GEORGE PRANGLEY WILSON, ...	Sheffield.
SAMUEL WILLIAM WORSSAM, ...	London.

In addition to these there have been thirty-nine Resignations of membership.

The Accounts for the year ending 31 December 1888 are now submitted to the Members (*see* pages 10–13), after having been passed by the Finance Committee, and certified by Mr. Robert A. McLean, chartered accountant, the auditor appointed by the Members at the last Annual General Meeting. The receipts during the year were £6,121 2*s.* 3*d.*, while the expenditure, actual and estimated, was £5,219 5*s.* 3*d.*, leaving a balance of receipts over expenditure of £901 17*s.* 0*d.* The financial position of the Institution at the end of the year is shown by the balance sheet: the total investments and other assets amount to £27,009 18*s.* 0*d.*; and allowing £600 for accounts owing but not yet rendered, the capital of the Institution amounts to £26,409 18*s.* 0*d.*, of which the greater part, as seen from the balance sheet, is invested in Railway Debenture Stocks, registered in the name of the Institution.

Since the reading and discussion of the third Report by the Research Committee on Friction, under the chairmanship of Mr. Tomlinson, which dealt with the friction of a collar bearing, arrangements have been under consideration with a view to carrying out a similar series of experiments on the friction of pivot bearings; and the machinery necessary is now being made.

Owing to the time and labour involved in working out the collateral results which the Research Committee upon Riveted Joints, under the chairmanship of the President, were desirous should be embodied by Professor Kennedy in his Report on the last set of specimen joints, the completion of this Report in the form desired has been much delayed; but it is now finished, and will shortly be in the hands of the Members (Proceedings 1888 pages 538–570).

The Research Committee appointed to draw up a standard system of Marine-Engine Trials, of which Professor Kennedy is the chairman, having at their first meetings discussed the general lines on which such trials should be conducted, have now been able to carry out on those lines several trials at sea, measuring feed-water, coal, power, &c., over continuous runs of fourteen to seventeen hours. These trials have been made under Professor Kennedy's direction and by the obliging permission of the ship-owners concerned; and the Report on the first of them, that on the s.s. "Meteor," has been adopted by the Committee, and will shortly be placed before the Members.

The work of collating the results of former experiments on the value of the Steam Jacket has been carried forwards by the Research Committee under the chairmanship of Mr. Henry Davey; and they have also made arrangements for carrying out, as soon as convenient opportunities arise, various experiments for which they have received obliging offers of facilities in connection with engines of different kinds.

In petitioning the House of Commons in April against the Architects' Registration Bill, the Council had the advantage of being actively and effectually supported by many of the Members, whose prompt exertions through their several Members of Parliament resulted in the withdrawal of the bill. As the statement and petition from the Council against the bill were circulated to the Members at the time and have since been published in the Proceedings (1888 pages 160–165), it would be unnecessary to refer to them now, were it not that in the subsequent annual report of the Council of the "Society of Architects" the withdrawal of the

bill is regretted, and the hope is expressed that ere long the measure will pass into law, at any rate in some modified form. It thus becomes desirable for the Members of this Institution to see that in any such modified measure their interests as Mechanical Engineers shall not be involved against their own wish with those of a different profession, however closely akin under certain circumstances.

To the Library of the Institution the donations made during the past year are enumerated in pages 14–20; and for these the Council gladly record their thanks to the several Donors. They again take this annual opportunity of inviting contributions of original pamphlets and records of experimental research, and of other works valuable for reference by the Members. The Council have had the gratification of receiving an admirable portrait of the late Sir Joseph Whitworth, Bart., Past-President, which has been presented to the Institution by Lady Whitworth and her co-executors.

The General Meetings in 1888 were the Annual General Meeting and the Spring Meeting, which were held in London; the Summer Meeting in Dublin; and the Autumn Meeting occupying two evenings in London. The Papers read and discussed at the eight sittings devoted to the purpose, and published in the Proceedings, were as follows:—

On Irrigating Machinery on the Pacific Coast; by Mr. John Richards.

On the Position and Prospects of Electricity as applied to Engineering; by Mr. William Geipel.

Third Report of the Research Committee on Friction: Experiments on the Friction of a Collar Bearing.

Description of Emery's Testing Machine; by Mr. Henry R. Towne.

Address by the President.

Description of a Balanced or Automatic Sluice for Weirs; by the Right Honourable the Earl of Rosse, F.R.S.

On the latest improvements in the Clock-Driving Apparatus of Astronomical Telescopes; by Sir Howard Grubb, F.R.S.

Description of Tramways and Rolling Stock at Guinness's Brewery; by Mr. Samuel Geoghegan.

Description of the Frictional Gearing used on a double Steam Dredger in the Port of Dublin; by Mr. John Purser Griffith.

Description of the Compound Steam Turbine and Turbo-Electric Generator; by the Honourable Charles A. Parsons.

Description of the Rathmines and Rathgar Township Water Works; by Mr. Arthur W. N. Tyrrell.

The attendances during 1888 were as follows:—at the Annual General Meeting 92 Members and 56 Visitors; at the Spring Meeting 79 Members and 49 Visitors; at the Summer Meeting 179 Members and 88 Visitors; and at the Autumn Meeting 92 Members and 51 Visitors.

After an interval of twenty-three years the Summer Meeting of the Institution was again held last year in Dublin, where the Members experienced a welcome renewal of the hospitable reception accorded to them in their former visit. The morning meetings for the reading and discussion of papers took place as before in Trinity College, on the invitation of the Provost and Senior Fellows, who were ably represented by the Rev. Dr. Haughton. After an Address by the President, dealing with the industrial welfare of Ireland, the Earl of Rosse described the simple construction of balanced or automatic sluice for weirs, which he has designed and erected at Parsonstown. Subsequent papers dealt with matters of mechanical interest connected with some of the numerous engineering and manufacturing establishments which the Members were invited to visit. To the larger and more distant works special excursions were arranged for the three days spent in Dublin; and a fourth day was occupied in inspecting the shipbuilding and engineering works and other important establishments in Belfast, after a visit to the spinning works and electric railway at Bessbrook on the way from Dublin. Alike in Dublin and in Belfast the Members were afforded the most agreeable opportunity of meeting their friends at the Conversazioni to which they were invited by the respective Local Committees, to whom they are indebted for the many facilities and hospitalities arranged for their gratification.

In connection with a Meeting so greatly enjoyed by all who attended it, the Council have already had the pleasure of announcing

to the Members (Proceedings 1888 page 413) that they have nominated as Honorary Life Members of the Institution the Right Honourable the Earl of Rosse, Chancellor of the University of Dublin and Chairman of the Local Committee, and the Rev. Dr. Haughton, Senior Fellow of Trinity College, Dublin, and Vice-Chairman of the Local Committee; while on the other hand (page 270) the honorary degree of "Master in Engineering" has been conferred by the University of Dublin upon two Past-Presidents of this Institution, Sir Lowthian Bell, Bart., and Mr. Ramsbottom.

As already announced in the President's Address at Dublin, the Council purpose holding the Summer Meeting of the Institution this year in Paris during the time of the International Exhibition; and at their request Mr. Henry Chapman, who so kindly acted as the Honorary Local Secretary for the two previous Paris Meetings of the Institution, has again obligingly promised his valuable aid in the same capacity for the forthcoming Meeting there.

In accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, retire from office this day. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1888	893	17	3			
,, Reprinting former Proceedings	46	15	0			
	940	12	3			
Less Authors' Copies of Papers, repaid	30	2	0	910	10	3
,, Library Catalogue, revision and reprinting				181	17	2
,, Stationery, Binding, and General Printing				204	7	11
,, Rent				550	0	0
,, Salaries and Wages				1,655	8	6
,, Coal, Firewood, and Gas				29	10	3
,, Fittings and Repairs				32	13	1
,, Postages				326	10	7
,, Insurance				5	2	3
,, Law Charges				27	12	0
,, Petty Expenses				44	18	7
,, Meeting Expenses—						
Printing	207	7	9			
Reporting	62	13	6			
Diagrams, Screen, &c.	109	4	11			
Travelling and Incidental Expenses	155	18	3	535	4	5
,, Dinner Guests				114	17	5
,, Research				490	11	3
,, Books purchased				10	1	7
				5,119	5	3
Accounts owing, not yet rendered, say	600	0	0			
Less Reserve in previous year for accounts since paid	500	0	0	100	0	0
Balance, being excess of Receipts over Expenditure, carried down				901	17	0
				£6,121	2	3

To Investment—						
£1,000 *Aire and Calder Navigation* $3\frac{1}{2}\%$ *Debenture Stock*				1,020	8	6
Cash Balance at this date	1,824	18	0			
Less Reserve to pay accounts not yet rendered, as above	100	0	0	1,724	18	0
				£2,745	6	6

FOR THE YEAR ENDING 31ST DECEMBER 1888. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
116 *New Members at £2*	232	0	0			
6 *New Associates at £2*	12	0	0			
14 *New Graduates at £1*	14	0	0			
5 *Graduates transferred to Members at £1*	5	0	0	263	0	0
„ Subscriptions for 1888—						
1422 *Members at £3*	4,266	0	0			
41 *Associates at £3*	123	0	0			
120 *Graduates at £2*	240	0	0			
5 *Graduates transferred to Members at £1*	5	0	0	4,634	0	0
„ Subscriptions in arrear—						
66 *Members at £3*	198	0	0			
1 *Associate at £3*	3	0	0			
4 *Graduates at £2*	8	0	0	209	0	0
„ Subscriptions in advance—						
31 *Members at £3*	93	0	0			
2 *Associates at £3*	6	0	0			
4 *Graduates at £2*	8	0	0	107	0	0
„ Interest—						
From Investments	555	0	5			
From Whitworth Bequest	227	1	3			
From Bank	32	2	7	814	4	3
„ Reports of Proceedings—						
Extra Copies sold				93	18	0
				£6,121	2	3

	£	s.	d.
By Balance brought down	901	17	0
Cash Balance 31st December 1887	1,843	9	6
	£2,745	6	6

Dr. BALANCE SHEET

	£	s.	d.
To Sundry Creditors—			
Accounts owing, not yet rendered, say	600	0	0
Capital of the Institution at this date	26,409	18	0
	£27,009	18	0

Signed by the following members of the Finance Committee:—

EDWARD H. CARBUTT.

JOSEPH TOMLINSON.
WILLIAM ANDERSON.

SIR JAMES N. DOUGLASS.
ALEXANDER B. W. KENNEDY.

AS AT 31st DECEMBER 1888. *Cr.*

		£ s. d.	£ s. d.
By Cash—*In Union Bank, on Deposit*		1,000 0 0	
" " " *on Current account* . .		324 18 0	
In Imperial Bank	491 4 2		
In hand	8 15 10	500 0 0	1,824 18 0
" Investments—(*cost* £16,490 2*s.* 2*d.*)			
£ 3,178 *London & North Western Ry.* 4% *Debenture Stock*			
2,200 *North Eastern* " " " "			
2,466 *Midland* " " " "			
1,800 *Great Western* " " " "			
1,270 *Great Eastern* " " " "			
891 *Metropolitan* " " " "			
2,325 " " $3\frac{1}{2}\%$ " "			
1,000 *Aire & Calder Navigation* " " "			
700 *Sir J. Whitworth and Co., Ld.* 5% " "			
Two hundred £10 shares Sir J. Whitworth and Co., Ld.			
The Market Value of these investments at 31st Dec. 1888 was about			21,900 0 0
" Subscriptions in Arrear £510, probable value			210 0 0
" Office Furniture and Fittings			245 0 0
" Library and Proceedings			2,670 0 0
" Drawings, Engravings, Models, Specimens, and Sculpture .			160 0 0
			£27,009 18 0

Audited and Certified by

ROBERT A. McLEAN, Chartered Accountant,
1 Queen Victoria Street, London, E.C.

LIST OF DONATIONS TO LIBRARY.

Presidential Address to the Engineering Association of New South Wales, by W. D. Cruickshank; from the author.

Catalogue de Machines Agricoles; from M. Auguste Albaret.

Rouleaux à Vapeur; from M. Auguste Albaret.

Standards of Length and their Practical Application, by the Pratt and Whitney Co.; from Dr. Coleman Sellers.

Adcock's Engineer's Pocket-Book for 1888; from the proprietor.

Official Handbook of the Cape of Good Hope, 1886; from Mr. Theodore Reunert.

Internal Ballistics, by J. A. Longridge; from the author.

Calendar of King's College, London, 1887–8; from the College.

Reprint of Preface to the Proceedings of the Society of Civil Engineers (Smeatonian); from Mr. George B. Rennie.

Table of the Solid Measurement of Timber, by Theodore Reunert; from the author.

Classified Lists and Distribution Returns of Establishment, Indian Public Works Department, to 30 June 1888; from the Registrar.

The Hypydor, a vessel for Descending and Travelling under Water, and Ascending and Navigating at the Surface, by R. Watkins; from the author.

Essai d'une Exposition rationnelle de la Théorie mécanique de la Chaleur, by Daniel Murgue; from the author.

Tin Mining in Larut, by Patrick Doyle; from the author.

Public Works Department Serials, from the India Office:—No. 9, Report connected with the project for the construction of Docks at Calcutta, Part II; No. 10, Report on Bridges of Boats used in the Punjab; No. 11, Report connected with the Zhara Karez Irrigation Scheme, Beluchistan; No. 12, Papers connected with the Betwa Canal Project in the North-Western Provinces; No. 13, Relative Merits of Broad and Metre Gauge Lines of Railway; No. 14, Papers relating to the Prince's Dock Extension, Bombay; No. 15, Failure of the Kali Nadi Aqueduct, Lower Ganges Canal; No. 16, Papers relating to the Oyster Reef Lighthouse.

Presidential Address to the Society of Engineers, by A. T. Walmisley; from the author.

Lectures on Water Supply, delivered at the School of Military Engineering, Chatham, by Alexander R. Binnie; from the author.

Warming, Ventilating, and Lighting of Railway Cars, by J. D. Barnett; from the author.

Spons' Engineers' Price-Book; from the publishers.

Gun Making in the United States, by Captain Rogers Birnie, Jun., with Discussion; from the Ordnance Office, Washington, U.S.

Testing of Materials of Construction, by Professor W. Cawthorne Unwin, F.R.S.; from the author.

Street Watering with Sea Water, by Stephen H. Terry; from the author.

Mechanical Equivalent of Heat, by C. J. Hanssen; from the author.

Reports on the working of heavy gradients in America, by Major W. Shepherd, R.E., and E. W. M. Hughes; from Mr. E. W. M. Hughes.

Contract and Specification for Pumping Engine No. 3, and three Fire-Box Tubular Boilers, Louisville Water Co., Kentucky; from Mr. E. D. Leavitt, Jun.

Rules and Regulations recommended for the Prevention of Fire Risks from Electric Lighting; from the Society of Telegraph-Engineers and Electricians.

Ericsson's Destroyer and Submarine Gun,
Heavy Ordnance for National Defence,
Modern Armour for National Defence,
Steel Gun Factories in the United States,
Torpedoes for National Defence,
Torpedoes, Torpedo Vessels, and Torpedo Warfare,
by Lieutenant W. H. Jaques, late U.S.N.; from the author.

Forced Draught, by J. R. Fothergill; from the author.

A National Canal between the Four Rivers a National Necessity, by Samuel Lloyd; from the author.

Use of Belting for the Transmission of Power, by John H. Cooper; from the author.

Board of Trade Report (No. 254) on the Explosion of a Boiler at Brockmoor Staffordshire; from Mr. Druitt Halpin.

List of Chinese Lighthouses, Light Vessels, Buoys, and Beacons, 1888; from the Inspector-General of Chinese Customs.

Ports maritimes de la France; from the French Ministry of Public Works.

Tabulated Abstract of Acts of Parliament relating to Water Undertakings, 1879 to 1887, by E. K. Burstal; from the author.

Report of Tests of Metals &c. made at Watertown Arsenal, Massachusetts, 1885; from the Ordnance Office, Washington, U.S.

Memorandum on Cause of Rupture of Jacket of 6-inch Breech-Loading Wire Gun, by James A. Longridge; from the author.

Journey round the World, by David Greig; from the author.

British Iron Trade Report, 1887; from Mr. J. S. Jeans.

Galway as a Packet Station, by W. G. Strype; from the author.

Naval Annual, 1887; from the Right Honourable Lord Brassey, K.C.B.

Marine Engine working at reduced speeds, by Paul du Buit and P. Sabathier; from Mr. Henry Chapman.

Description of Foster and Campbell's Evaporating Apparatus for sugar cane juice and other liquids; from Mr. James Foster.

Catalogue of Astronomical Instruments and Observatories; from Sir Howard Grubb, F.R.S.

Notes on the Construction of Ordnance; and Annual Reports of the U.S. Chief of Ordnance, 1887 and 1888; from the Ordnance Office, Washington, U.S.

Steam and Gas Curves, by Professor Robert H. Smith; from the author.

Antwerp Exhibition 1885, Reports vols. I, IV, and VI; from Mr. William Anderson.

Manganese Steel, by Robert A. Hadfield; from the author.

Practicable Decimal System for Great Britain and her Colonies, by R. T. Rohde; from the author.

Investigations into the Internal Stresses in Cast Iron and Steel, by General N. Kalakoutsky; from Mr. William Anderson.

Report of the Archæological Survey of Bengal, 1887, by J. D. Melik-Beglaroff; from Mr. E. H. Carbutt.

Notes on the Water Meter System of Providence, Rhode Island, from 1872 to 1887, by Edmund B. Weston; from the author.

Civil Engineer's Pocket Book for 1888, by John C. Trautwine; from Mr. John C. Trautwine, Jun.

Catalogue of Dredging Appliances; from Messrs. William Simons and Co.

Advice to Mechanical Engineering Students, by Professor John Perry, F.R.S.; from the author.

Architects' Register, 1888; from the editor.

Copper Steam Pipes for Modern High-Pressure Engines, by William Parker; from the author.

Calendars for 1888–89, from the following Colleges:—City of London College; Firth College and Sheffield Technical School; Glasgow and West of Scotland Technical College; University College, Bristol; University College, Dundee; Yorkshire College, Leeds.

Ten Lectures delivered in the Sassoon Mechanics' Institute, Bombay; from the Institute.

Hydraulic Problems on the Cross-sections of Pipes and Channels, by Professor Henry Hennessy, F.R.S.; from the author.

Brakes for Retarding the Motion of Carriages in Descending Inclines, by William Philipson; from the author.

Catalogue of Pumping Engines, Steam Pumps, and Hydraulic Machinery; from the Worthington Pumping Engine Co.

Displacements and Area Curves of Fish, by H. de B. Parsons; from the author.

Calendar 1888–9, and Library Catalogue of the Royal Technical High School, Berlin; from the Rector.

Gaseous Fuel, by J. Emerson Dowson; from the author.

Central-Station Electric Lighting, by Killingworth Hedges; from the author.

Presidential Address to the North-East Coast Institution of Engineers and Shipbuilders, by F. C. Marshall; from the author.

Specification for a Lancashire Boiler, with plan of setting and mode of staying, by William H. Fowler; from the author.

Régulateurs de Vitesse, by Georges Marié; from the author.

Régulateurs dans les Distributions d'Électricité, by Georges Marié; from the author.

Description of the Barry Dock and Railways, by John Robinson; from the author.

Life of Sir William Siemens, F.R.S., D.C.L., LL.D., by William Pole, F.R.S.; from Mr. Alexander Siemens.

Supplement to the Twentieth Annual Report of the Department of Marine, Canada, 1887; from the Canadian Government.

Motores de Viento, by Fernando Aramburu; from the author.

Report on Weights and Measures, 1888; from the Board of Trade.

Railways for Even Country, their Construction and Cost, by George Phillips; from the author.

Annual Report of the Yorkshire College, Leeds, 1887–88; from the College.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Board of Trade Reports on Boiler Explosions, 1879–82, issued before the passing of the Boiler Explosions Act 1882; from the Manchester Steam Users' Association.

Lecture on the Engineer of the Future, by Professor Archibald Barr; from the author.

Presidential Address to the Junior Engineering Society, by Professor W. Cawthorne Unwin, F.R.S.; from the author.

Presidential Address on the Use of Theory, by Professor W. Cawthorne Unwin, F.R.S.; from the Junior Engineering Society.

Engineer's Annual Report as to the Progress of the Vyrnwy Water Works, by George F. Deacon; from the author.

Presidential Address to the Bradford Philosophical Society, by Alexander R. Binnie; from the author.

Presidential Address to the Civil and Mechanical Engineers' Society, by Reginald E. Middleton; from the author.

Report of Council of University College, Bristol, 1888; from the College.

Pocket Book of Engineering, by Rai Bahadar Ganga Ram; from the author.

Two-nosed Catenaries and their application to the design of Segmental Arches, by Professor T. Alexander and A. W. Thomson; from the authors.

Cause of Light, by the Rev. G. T. Carruthers; from the author.

Planets upon Cardioides, by the Rev. G. T. Carruthers; from the author.

Engraving of Compound Express Locomotive Engine "Marchioness of Stafford," London and North Western Railway; from the editor of "The Engineer."

Gas Engineer's Pocket Almanack, 1889; from Messrs. Sugg.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.
Reports of the Royal Academy of Science, Belgium.
Reports of the Royal Institute of Engineers, Holland.
Engravings from the École des Ponts et Chaussées, Paris.
Annales des Ponts et Chaussées, Paris.
Proceedings of the French Institution of Civil Engineers.
Journal of the French Society for the Encouragement of National Industry.
Reports of the French Association for the Advancement of Science, 1885 and 1886; from the Association.
Journal of the Marseilles Scientific and Industrial Society.
Annales de l'École Polytechnique de Delft.
Proceedings of the Engineers' and Architects' Society of Canton Vaud.
Proceedings of the Engineers' and Architects' Society of Austria.
Proceedings of the Architects' and Engineers' Society of Hannover.
Proceedings of the Engineers' and Architects' Society of Prague.
Proceedings of the Italian Engineers' and Architects' Society.
Proceedings of the Engineers' and Architects' Society of Milan.
Proceedings of the Industrial Society of St. Quentin et de l'Aisne.
Proceedings of the Industrial Society of Mulhouse.
Proceedings of the Industrial Society of the North of France.
Proceedings of the German Society of Engineers.
Proceedings of the Russian Imperial Institute of Engineers.
Proceedings of the Swedish Society of Engineers.
Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the United States Naval Institute.
United States Patent Office Gazette.
Transactions of the Canadian Society of Civil Engineers.
Proceedings and Journal of the Asiatic Society of Bengal.
Proceedings of the Engineering Association of New South Wales.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Society of Telegraph-Engineers and Electricians.
Transactions of the Institution of Civil Engineers of Ireland.

Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Transactions of the Chesterfield and Midland Counties Institution of Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the Mining Institute of Scotland.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Transactions of the Hull and District Institution of Engineers and Naval Architects.
Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh, 1883–84, 1884–85, 1885–86, and 1886–87.
Proceedings of the Royal Institution of Great Britain.
Transactions of the Surveyors' Institution.
Transactions of the Sanitary Institute of Great Britain.
Journal of the Royal United Service Institution.
Professional Papers of the Royal Engineers' Institute.
Proceedings of the Royal Artillery Institution.
Journal of the Royal Agricultural Society of England.
Journal of the Royal Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions and Journal of the Royal Institute of British Architects.
Transactions of the Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Transactions of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions and Proceedings of the Royal Irish Academy.
Transactions and Proceedings of the Royal Dublin Society.
Journal of the Liverpool Polytechnic Society.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Midland Steam Boiler Inspection and Assurance Company, Records of Boiler Explosions in 1887; from Mr. Edward B. Marten.

Report of the National Boiler Insurance Company; from Mr. Henry Hiller.

Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.

Tenth Annual Report of the National Association of British and Irish Millers; from the Association.

Report of the London Association of Foremen Engineers and Draughtsmen.

Seventh Report of the Newcastle-upon-Tyne Public Libraries Committee.

Thirty-fifth Annual Report of the Liverpool Free Public Library.

Catalogue of Additions to the Radcliffe Library, Oxford.

The following Periodicals from the respective Editors:—

Revue générale des Chemins de fer.
Revue universelle des Mines.
Revue industrielle.
Portefeuille économique des Machines.
Stahl und Eisen.
Der Civil-Ingenieur.
Glaser's Annalen.
Giornale del Genio Civile.
Ingeniero y Ferretero Español y Sud Americano.
The American Engineer.
The American Manufacturer.
The Engineering and Mining Journal.
The National Car and Locomotive Builder.
The Railroad and Engineering Journal.
The Railway Master Mechanic.
The Indian Engineer.
Indian Engineering.
The Engineer.
Engineering.
The Railway Engineer.
The Marine Engineer.
Iron.
The Iron and Coal Trades Review.
Ryland's Iron Trade Circular.
The Ironmonger.
The Mechanical World.
The Mining Journal.
The Colliery Guardian.
The Machinery Market.
The Builder.
The Builders' Weekly Reporter.
The Electrical Review.
The Electrical Engineer.
The Chamber of Commerce Journal (from Mr. Henry Chapman).
The Contract Journal.
The Gas and Water Review.
The Gas World.
The Plumber and Decorator.
The Shipping World.
The Fireman.
Industries.
Invention.
The Universal Engineer.
The Railway Record.
The Railway Press.
The British Trade Journal.
The Practical Engineer.
Electrical Plant.
Scientific News.
Mechanical Progress.
Martineau and Smith's Hardware Trade Journal.
Phillips' Monthly Machinery Register.

The PRESIDENT, in moving the adoption of the Annual Report of the Council, said they believed, and he thought the Members would agree with them, that the Institution was in a flourishing position. The present number of Members was over 1800, showing a net gain of 65 notwithstanding resignations and deceases. Among the latter were the names of several Members who had taken a leading rank among engineers. He need scarcely refer at any length to Mr. Thomas Russell Crampton, a former Vice-President, who had always taken a prominent part in engineering, and had been a member of many other societies also; he had done good work, which would no doubt live after him, and many of those who had been his pupils would reap the benefit of what they had learnt from him. Another name to which he should like to refer was that of Mr. Charles Markham, of Chesterfield, with whom he had himself worked formerly for many years on the Midland Railway, and whom therefore he particularly regretted. Another old Member to whom he might refer was Mr. Charles W. Wardle, of Leeds, who had been one of the pioneers in locomotive engine building, having served his time with a very old firm who had had a great many pupils, Messrs. E. B. Wilson and Co., of Leeds; a large number of engineers therefore would remember him and feel sorry that he had been taken from them. Without going through the rest of the names, he was sure that all regretted losing so many of their fellow-members during the past year.

With regard to the accounts, he was glad to find that the expenditure had been increasing. It was no use going on collecting money if nothing was to be done with it. The Council had been spending money pretty freely in connection with the labours of the Research Committees, and he believed that those Committees were doing very good work. The Council and the Members who were on the Research Committees had been working very hard, and they had the satisfaction of knowing that they were doing something for the benefit of engineering, and for the benefit of the Institution. The capital of the Institution now amounted to upwards of £26,000; and in the present balance sheet for the first time, mainly he believed at the suggestion of Mr. Price-Williams, the Council had included in the capital the present market value of the different stocks, instead of

(The President.)

only the value at which they had been purchased; it would be seen that there was thus an increase of £5,400 in the capital, owing to the rise in price which had taken place in the several investments. Some of this increase he thought might also be spent in research; and he hoped the Members would back up the Council in spending as much money as possible in that way.

In regard to the Architects' Registration Bill, although it had been withdrawn, he was certain they had not seen the last of it; and whenever it was again introduced he was sure the Council would again trouble the Members to write to their respective representatives in Parliament requesting them to oppose the bill, unless it was brought forward in a much better shape than that in which it had previously been presented.

Her Majesty had been graciously pleased to confer honours upon two of the Members of the Institution. She had made Sir Frederick Bramwell a baronet; and as he was one of the Past-Presidents of the Institution, they felt that this honour conferred upon him was an honour conferred upon the Institution. She had also conferred the honour of knighthood upon Mr. John Turney, the very energetic mayor of Nottingham, who had taken an active part in promoting the welfare of his town, and had been very liberal in devoting his means to the advancement of its interests, especially in connection with the Royal Agricultural Show. They were all very glad therefore that Her Majesty had been pleased to make him a knight.

As the Members were aware, he had himself been making a five months' tour in America, during which he had gone over several of the very large railways in the United States and Canada and Mexico; and he was more and more convinced that, although the old saying was that trade followed the flag, it really followed the engineer; and that, wherever English engineers went, as a rule the material for the railways was bought in England. It was therefore very necessary that this Institution and all kindred societies should do all that lay in their power to encourage young men to join them, and when they were abroad to keep up a friendly feeling between themselves and the institutions in this country. In that way they would cherish a feeling of loyalty, not only to the institutions,

but to the country at large. This feeling he had heard strongly expressed in Canada. At the time when annexation to the United States was being talked of, he had met with many Canadian engineers, some of them Members of this Institution, all of whom were as loyal as could be and entertained the kindest regard for the old country. The Members might depend upon it that, if they would only look after the young engineers before they went out, and make them members of this or other Institutions, they would in that way be benefiting the trade of the country.

He had great pleasure in moving the adoption of the Report of the Council, and of the accounts; and he should be glad to hear any remarks from any Member on the subject.

No Member rising to speak, the President put the motion, which was agreed to.

The PRESIDENT announced that the Ballot Lists for the election of Officers for the present year had been opened by a committee of the Council, and that the following were found to be elected:—

PRESIDENT.

CHARLES COCHRANE, ... Stourbridge.

VICE-PRESIDENTS.

WILLIAM ANDERSON, ... London.
SIR JAMES N. DOUGLASS, F.R.S., . London.
ARTHUR PAGET, ... Loughborough.

MEMBERS OF COUNCIL.

BENJAMIN A. DOBSON, . . . Bolton.
JOHN G. MAIR, ... London.
HENRY D. MARSHALL, . . . Gainsborough.
EDWARD B. MARTEN, . . . Stourbridge.
BENJAMIN WALKER, . . . Leeds.
J. HARTLEY WICKSTEED, . . . Leeds.
THOMAS W. WORSDELL, . . Gateshead.

The Council for the present year will therefore be as follows:—

PRESIDENT.

CHARLES COCHRANE, . . .	Stourbridge.

PAST-PRESIDENTS.

THE RIGHT HON. LORD ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . .	Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., .	Northallerton.
SIR FREDERICK BRAMWELL, BART., D.C.L., F.R.S., ...	London.
EDWARD H. CARBUTT, . . .	London.
THOMAS HAWKSLEY, F.R.S., . .	London.
JEREMIAH HEAD, ...	Middlesbrough.
JOHN RAMSBOTTOM, . . .	Alderley Edge.
JOHN ROBINSON, ...	Leek.
PERCY G. B. WESTMACOTT, . .	Newcastle-on-Tyne.

VICE-PRESIDENTS.

DANIEL ADAMSON, ...	Manchester.
WILLIAM ANDERSON, . . .	London.
SIR JAMES N. DOUGLASS, F.R.S., .	London.
ARTHUR PAGET, ...	Loughborough.
RICHARD PEACOCK, M.P., . . .	Manchester.
JOSEPH TOMLINSON, ...	London.

MEMBERS OF COUNCIL.

BENJAMIN A. DOBSON, . . .	Bolton.
SIR DOUGLAS GALTON, K.C.B., F.R.S., .	London.
SAMUEL W. JOHNSON, . . .	Derby.
ALEXANDER B. W. KENNEDY, F.R.S., .	London.
WILLIAM LAIRD, ...	Birkenhead.
JOHN G. MAIR, . . .	London.
HENRY D. MARSHALL, . .	Gainsborough.
EDWARD B. MARTEN, ...	Stourbridge.
EDWARD P. MARTIN, ...	Dowlais.
SIR JAMES RAMSDEN, ...	Barrow-in-Furness.
E. WINDSOR RICHARDS, . . .	Low Moor.

T. HURRY RICHES, ...	Cardiff.
BENJAMIN WALKER, . . .	Leeds.
J. HARTLEY WICKSTEED, . .	Leeds.
THOMAS W. WORSDELL, . .	Gateshead.

The PRESIDENT said it now became his pleasing duty to induct into the presidential chair his successor, Mr. Charles Cochrane. In electing him he felt sure that the Members had been doing honour to themselves. Any member who had filled the positions which Mr. Cochrane had occupied in the engineering world was unquestionably a man worthy to be their President. He might indeed have been President some years earlier, if his health and his modesty had allowed him to take that position. At last the Council had prevailed upon him to accept the nomination for the presidency. As the Members were aware, he was not only a Staffordshire man but a Middlesbrough man. He was the head of the firm of Messrs. Cochrane and Co., ironmasters, of Woodside Iron Works, Dudley; and he was also a member of the firm of Messrs. Cochrane, Grove and Co., of Ormesby Iron Works, Middlesbrough. He had devoted a large part of his time to improving the hot-blast stove for the blast-furnace, and had been very successful in the adaptation of regenerative hot-blast stoves to iron-smelting. He had also devoted a great deal of time to the improvement of iron-smelting itself, not only in Staffordshire but also in Middlesbrough; and in that work likewise he had been very successful, as would be gathered from the numerous valuable papers which he had from time to time contributed to the Institution Proceedings on this important subject. But he had not only devoted his time to raw products; he had also been largely concerned in bridge building and in improving the mechanical appliances for that purpose. His firm had constructed some of the largest bridges in London, including Westminster Bridge and the railway bridges at Charing Cross and Cannon Street; also the large bridge over the Mersey at Runcorn for the London and North Western Railway, and the suspension bridge at Clifton over the Avon, besides a large number of bridges for India and the Colonies.

(The President.)
He had devoted his energies to these works at a time when labour was dear and tools were not so good as now; and he believed he had been the first to adopt the multiple drill for drilling all the plates of big bridges, just as Mr. Adamson had been the first to adopt drilling for boilers. As a consequence drilling had now been adopted by nearly every other bridge builder or boiler maker; and he believed that during the last few years there had hardly been a bridge built in England in which the holes had not been drilled, however the case might be abroad. The Members would therefore agree with him that Mr. Cochrane had great claims upon them, and that the knowledge he possessed would be very valuable to the Institution. He trusted he would have as pleasant a presidency as he had himself had, and that he would enjoy good health, and would receive the support of all the Members in the position to which they had now elected him.

Mr. Charles Cochrane, President elect, on then taking the chair, said he was deeply conscious of the honour which the Members had conferred upon him by electing him as President. In acknowledging Mr. Carbutt's kind remarks, he desired at the outset to mention that the introduction of the multiple drill for bridge work at Woodside must be attributed to his uncle, Mr. John Cochrane, and not to himself (Proceedings 1860, page 201). Upon the other points mentioned, he must plead guilty to the charge of having done something in the development of blast-furnaces.

Though debarred by his doctor's orders from continuing in the occupancy of the chair throughout the present evening, he was sure the Members would not regard this as an indication of any failure on his own part to appreciate the duties which devolved upon the President of the Institution; these he promised to discharge to the best of his ability.

Mr. Arthur Paget, Vice-President, felt sure he should be simply expressing what all the Members had in their hearts, if he reminded them that they could not allow Mr. Carbutt to retire from being their President, after his admirable conduct of the business of the

Institution for the last two years, without some acknowledgment, however inadequate. Having had the pleasure of Mr. Carbutt's acquaintance and friendship for a number of years, he ventured to draw attention to the fact that Mr. Carbutt had now been a Member, and a very active and useful Member, of the Institution for twenty-nine years. He joined in 1860, and was elected a member of Council in 1875. When one of the most important steps ever taken by the Institution was decided on — namely the removal of the head-quarters from Birmingham to London in the year 1877—the resolution to that effect was seconded by Mr. Carbutt, and his advocacy assisted much in carrying it. When two years ago Mr. Carbutt was asked without notice to accept the nomination for the presidency, in consequence of the unfortunate ill-health at that time of Mr. Cochrane who would otherwise have been elected then, he stepped into the breach to fill the office at that time of difficulty; and it was needless to say how well he had filled it, and how much he had done to conduce to the honour and standing of the Institution. To one particular fact he wished to call special attention. For many years the Council had struggled to render the attendance at the annual dinner worthy of the Institution, and notwithstanding all their endeavours the attendance had fallen off to about 55 Members, who dined together mournfully and miserably. Mr. Carbutt had been one of the first to start a new system, and during his presidency the numbers had run up to 250 and more, and had been limited only by the accommodation that could be obtained. Much of that was due to Mr. Carbutt's influence. Then again he might remind them that under Mr. Carbutt's admirable superintendence the Institution had had the honour of entertaining as guests at these dinners in the last two years the Duke of Cambridge, the Marquis of Hartington, Lord Charles Beresford, and other noblemen and gentlemen of national distinction. This showed that Mr. Carbutt had worked hard for the Institution in many ways. In referring to the last year's accounts of the Institution, and pointing out that their capital now amounted to upwards of £26,000, Mr. Carbutt had also very properly stated, what he was sure the Members would all feel, that it was absurd to go on saving money

(Mr. Arthur Paget.)

for nothing. Mr. Carbutt however had not told them what he himself now felt bound to state, that Mr. Carbutt had also done his best and had nearly succeeded in providing what the Institution now wanted for its full establishment and development in London, namely a house and home of its own. If the Institution did not yet possess that advantage, it was no fault of Mr. Carbutt, who had not only worked hard for its realisation, but had even offered to expose himself to very considerable pecuniary liability in providing a site, so that they might have a home of their own before many years were over. This simple reminder, he thought, of what he had no doubt most of the Members knew, would enable them to see that in offering these few remarks he felt that he had expressed himself only half as well as he wished to have done, when he asked them to pass a hearty vote of thanks to Mr. Carbutt for the admirable services which he had rendered to the Institution during the past two years.

Sir James N. Douglass, Vice-President, had very great pleasure in endorsing every word uttered by Mr. Paget. He was sure the Members were all of one opinion in the matter. It was only necessary to have worked with Mr. Carbutt as the Members of the Council had worked, in order to know his zeal, his kindness, and his attention in season and out of season to the interests of the Institution; and he had worked with a large measure of success. He heartily seconded the resolution, and was sure that the meeting would accept it with the utmost cordiality.

The resolution was put, and was carried with acclamation.

Mr. Carbutt, in again taking the chair at the request of Mr. Cochrane, thanked the Members very heartily for the kind manner in which they had accepted the resolution so flatteringly proposed by Mr. Paget, and seconded by Sir James Douglass. He believed in the Institution, and had no doubt that if it was allowed ample scope it would do a great work. There was he believed a great work to be done by mechanical engineers. He was one of those who

considered that mechanical engineers had a great destiny before them, and that the happiness and welfare of mankind depended as much upon them as upon any body of men in the world. When the Members had elected him as President two years ago, he was as it were out of work; he was not in the House of Commons, and having plenty of time he had determined to do what he could; and by the help of the Council, and with the kind assistance of the Members, he had been able he hoped to keep unsullied the position which he had occupied, and so to hand it on to Mr. Cochrane. He thanked the Council for the manner in which they had treated him; all had been harmonious between them, and if it were not for the Council he did not think the Institution would be in anything like the flourishing position which it now occupied. They had of course sometimes differed in opinion; among all persons who wanted to carry on any work with spirit and energy there must be some differences of opinion; but all matters had been discussed calmly and moderately, and he hoped this would always continue to be the case, so that the Institution might still retain its present flourishing condition.

The CHAIRMAN said it was now the duty of the Members to appoint an Auditor for the present year.

On the motion of Mr. FREDERICK COLYER, seconded by Mr. JOHN G. MAIR, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at a remuneration of Ten Guineas, being the same as heretofore.

In pursuance of the notice given at the previous General Meeting on behalf of the Council, the two following additions to the By-laws were proposed from the chair :—

New By-law, to follow immediately after the existing By-law 10 :—" The Council may at their discretion reduce or remit the

"Annual Subscription, or the arrears of Annual Subscription, of any "Member who shall have been a subscribing Member of the "Institution for twenty-five years, and shall have become unable to "continue the Annual Subscription provided by these By-laws."

Addition to be made at the end of the existing* By-law 34 :— "and whose subscriptions shall not have been remitted by the "Council as hereinbefore provided."

The CHAIRMAN said he need hardly explain that the Institution had in its ranks some who had been Members for a great number of years, but whose circumstances were not now such as to justify them in continuing their subscription. It occasionally happened that Members who had paid their subscription regularly for twenty-five or thirty years were not able to continue it, in consequence of bad times. Under such circumstances he thought it was only right that they should be continued as Members; and the new by-law was proposed with that object in view. The period named was twenty-five years, but he should himself be glad if some Member would propose that it should be twenty years; cases sometimes came before the Council where a Member had subscribed for only twenty years, but was unable to continue his subscription; and in such an instance he thought the Council ought to have the power of retaining his name on the list of Members.

Mr. J. MACFARLANE GRAY proposed as an amendment that the following addition be made to By-law 10:—"The Annual Subscription "of any Member who shall have been a subscribing Member of the "Institution for twenty-five years shall thereafter be £1 per annum." This rule he wished to apply to all alike, because he considered that if they paid £3 a year for twenty-five years it would thereafter be sufficient if they paid £1 per annum; they would then be paying for all they got, namely the Proceedings of the Institution. If the Members desired to have another by-law for those who could not pay at all, they could have it. He was encouraged to propose this amendment by what had been said about the wealth of the Institution,

* Now re-numbered as By-law 13.

and the excess of its income over its expenditure; and his proposal he thought was financially correct and workable. Occupying himself the position of a government servant who would have in a few years to retire on a small pension, he believed there were many Members similarly circumstanced who would rather cease to be Members than continue their membership on any different footing from the rest of the Members.

Mr. DRUITT HALPIN seconded the amendment, because he thought under the circumstances it was quite reasonable that the matter should be placed on the footing explained by Mr. Macfarlane Gray. Instead of individual Members being obliged to plead singly before the Council, he considered that at the end of twenty-five years, if this longer limit of time was kept, the case of such Members might be fairly met by the subscription of £1 per annum. The Institution did not want to make a profit by such Members. The Council were not spending all the money of the Institution, and he hoped they would in future spend more; but as long as there was a balance left and something in hand for experimental research, he did not think that anything further was wanted.

Mr. E. WINDSOR RICHARDS, Member of Council, said the Council had had before them a few cases of Members who had been in the Institution the greater part of their lives, but at the end of twenty-five years or more, owing to adverse circumstances, were not able to continue as Members because they could not pay the £3 annual subscription. The Members he referred to were real engineers from apprenticeship, and holding formerly good positions in the country; but bad times had come upon them, and they had been really unable to continue their annual subscription. The Council had always tried to help them by retaining their names on the list of Members for a year or two longer, in order to see whether circumstances would improve with them so that they might be able to pay up their arrears. Some however, although they had no doubt tried their best, had been unable to make the required payments; and he was sure that, if the Members only knew all the circumstances which had been brought

(Mr. E. Windsor Richards.)

before the Council, they would agree to the additional by-law proposed from the chair. The present by-laws did not enable Members when in a good position to compound for life-membership. Many of them might at certain times be glad to pay such a composition as should relieve them from any further liability for the rest of their lives; but there was now no by-law enabling them to do so, and the consequence was that they had to go on year after year, and if at last trouble overtook them they were unable to pay the subscription when it became due. Was it not a pity that the Institution should have to turn out those who under such circumstances were really unable to pay, as had happened in several cases? If the Members would not consent to the shorter period of twenty years, he hoped they would at least consent to a period of twenty-five years for the application of the proposed new by-law; but he hoped they would consent to the shorter period, leaving the matter in the hands of the Council, who were of course most anxious to carry out the wishes of the Members. They might depend upon it that, if a case was not a deserving one, an old Member would not be let off without paying his subscription.

Mr. DANIEL ADAMSON, Vice-President, said he was reluctant to enter into a discussion of a rule which had been adopted and recommended by the Council themselves; but he agreed with the Chairman that it would be a desirable thing if the period of twenty years were substituted for twenty-five. A case had come before the Council that day, in which, if such a rule had been in existence with the period of twenty years, it would have been of great service in enabling the Council to continue the membership of a very worthy man. It had been suggested that an engineer might have lost his means; but no engineer with health and strength, he considered, would lose his means. If however his health failed, and he was not able to follow his vocation and could not pay his subscription, and if his fellow members virtually said to him that the Institution was rich and could do without his subscription and would still send him their Proceedings, what harm could result? If after a few years such a Member recovered his position, he could then say, as every

honourable and right-minded man would say, that he could now well afford to pay up his arrears of subscription, and he would thank them from his heart for relieving him in a temporary difficulty. The Institution he hoped would readily enter into such an arrangement. The Council might not act upon it, unless it was a case of necessity; but if they did act upon it, he was sure the Members would be the last in the world to say that they had done wrong. He therefore hoped the proposed additions to the by-laws would be passed, with the amendment which he now moved that twenty years be substituted therein for twenty-five.

Mr. ARTHUR PAGET, Vice-President, seconded the amendment moved by Mr. Adamson, that twenty years be substituted for twenty-five in the proposed additions to the by-laws as moved from the chair. In regard to Mr. Gray's amendment, he would point out that the object of the Council's proposal was that they might be empowered in cases such as had come before them—of Members who in consequence of ill-health had fallen into circumstances in which the subscription was a matter of importance to them—to remit the subscription after a certain period. This was very different from Mr. Gray's proposition, which would have the effect of reducing from £3 to £1 the subscription of most of the Members of the Council, as well as of many other Members who could well afford £3; and he thought he was representing not only himself but the whole of the Council in declining any such offer with thanks.

The CHAIRMAN said he was obliged to rule Mr. Macfarlane Gray's amendment to be out of order, no notice having been given of it. The proposed resolution could be amended; but no amendment could be received which entirely did away with the original proposal. Accordingly he would now put the proposal for the additions to the by-laws as already moved from the chair, with the substitution of twenty years in place of twenty-five years, agreeably with the amendment to this effect.

The proposal so amended was agreed to.

The following Paper was then read and discussed :—

On the use of Petroleum Refuse as Fuel in Locomotive Engines; by Mr. THOMAS URQUHART, of Borisoglebsk, Russia. Supplementary Paper.

At Ten o'clock the Meeting was adjourned till the following evening. The attendance was 77 Members and 55 Visitors.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Thursday, 31st January 1889, at Half-past Seven o'clock p.m.; CHARLES COCHRANE, Esq., President, in the chair.

The following Paper was read and discussed :—

On Compound Locomotives; by Mr. R. HERBERT LAPAGE, of London.

At Ten o'clock the Meeting was adjourned till the following evening. The attendance was 80 Members and 82 Visitors.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, 1st February 1889, at Half-past Seven o'clock p.m.; CHARLES COCHRANE, Esq., President, in the chair.

The following Paper was read and discussed :—

On the latest development of Roller Flour Milling; by Mr. HENRY SIMON, of Manchester.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated at twenty minutes past Ten o'clock. The attendance was 49 Members and 54 Visitors.

SUPPLEMENTARY PAPER ON THE USE OF PETROLEUM REFUSE AS FUEL IN LOCOMOTIVE ENGINES.

By Mr. THOMAS URQUHART, Locomotive Superintendent, Grazi and Tsaritsin Railway, South East Russia.

The object of the present paper, which forms a supplement to the author's previous paper on the same subject in 1884 (Proceedings 1884, page 272), is to bring before the Institution the more recent results of his experience in the use of Petroleum Refuse as fuel on an unprecedented scale upon the Grazi and Tsaritsin Railway, South East Russia. The very general and increasing interest arising out of the former paper and its discussion bears testimony to the growing importance of the subject in all countries; and any authentic data from the results of practical experience extending over a number of years are sure therefore to be more or less acceptable. Since the publication of the original paper in 1884 nothing new in principle has been discovered; the same appliances still continue in use, having undergone only the very slight modifications suggested by experience and by constant observation with a view to simplicity and cheapness.

Since 1 November 1884 the whole of the 143 locomotives under the author's superintendence have been fired with petroleum refuse, besides fifty stationary boilers, both horizontal and vertical, two scrap-welding furnaces, four tire-heating fires, two brass-melting furnaces, and three plate and spring heating furnaces. Petroleum refuse is in fact the fuel used for all steam-generating purposes, to the complete exclusion of all solid fuel, except a very small quantity of wood for starting the fires in horizontal boilers of pumping engines. For all metallurgical operations also at the central works at Borisoglebsk petroleum is used as fuel, except for the smiths' fires and the foundry cupolas; and from experiments

now in progress the author does not despair of overcoming the present difficulties in its application to these two remaining exceptions.

Spray Injector.—For all goods locomotives exactly the same spray injector is used now as formerly (Proceedings 1884, Plate 57); but for passenger locomotives it is provided with a longer nozzle, as shown in Figs. 1 to 3, Plate 1, which is indispensable on account of the trailing axle being so close to the back of the fire-box, Fig. 3, and thus coming in the way of the injector. The main dimensions of the spray injector in Plate 1 are exactly the same as in Plate 57 of 1884, the only difference being in the length of the nozzle. The divider or vertical grid at one time used inside the fire-box, close in front of the orifice of the spray injector, for the purpose of still more thoroughly breaking up the spray jet, is now discarded in favour of bringing the brickwork closer up to the orifice, so that the spray may break itself up against a rugged brick wall.

Regenerative or Accumulative Combustion - Chamber. — Many experiments were made with a variety of forms of brickwork inside the furnace or fire-box. For locomotives the author's mature experience has reduced these to the two constructions, shown in Plate 2 for six-wheeled goods and passenger engines, and in Plate 3 for heavy eight-wheeled goods engines. In the latter case the spray injector is placed under the fire-box ring, Fig. 9, and delivers the jet through the rear end of the ashpan, these engines having deep ashpans which admit of this arrangement. In Plate 4 is shown the arrangement of brickwork used for Galloway and marine boilers; in Plate 5 for horizontal boilers fired underneath; and in Plate 6 for vertical boilers. For the latter, even when quite cold, the fire is started with petroleum alone, without any wood, by means of a simple contrivance which serves its purpose very well; as shown in Figs. 16 and 17, a cast-iron pan P, Figs. 20 and 21, is inserted through a fire-door above the brick vault, and is filled with petroleum refuse poured in from the outside and ignited, air being admitted to the burning liquid through nipples in the bottom of the

pan; as soon as steam is raised, the pan is withdrawn and the door closed, and the spray injector started at the bottom of the furnace, Fig. 19. The vertical boiler here shown is 7 ft. 9 ins. high and 3 ft. 6 ins. diameter, with 50 tubes of 2 inches diameter, and 155 square feet total heating surface; working at 55 lbs. per square inch above the atmosphere, it drives an engine of 8 HP. nominal, used for pumping water, and burns 27 lbs. of petroleum refuse per hour. In Plate 7 is represented a combination of furnace for petroleum and wood firing, as actually used in the wagon repairing shops at Borisoglebsk, where quantities of chips, shavings, old timbers, and saw dust are to be had for fuel; but should there be any scarcity of wood fuel, the petroleum-burning appliances fitted to the furnace as here shown can be started at a moment's notice. It is still the author's opinion, as it has been all along, that the form, mass, and dimensions of the brickwork are certainly the most important elements in this plan of utilising liquid fuel, if not indeed in any plan.

Cost of Altering Locomotives for Petroleum firing.—In Table X appended is shown the cost of altering a locomotive of 5 feet gauge, according to the two different plans followed by the author on the Grazi and Tsaritsin Railway, the difference relating more to the tender than to the engine. The figures given of the costs include all details of the alterations, and are at local Russian prices; and as the rate of exchange at the time of the former paper in 1884 made one paper rouble equal to two shillings, this value is adhered to throughout the present paper also. In the six-wheeled engines the original coal space in the tender was found to be of sufficient capacity for containing the necessary supply of liquid fuel, and required therefore simply to be plated over, as shown in Plate 8; it is plated top and bottom, and a bulkhead is added across the front; the tank so formed contains 123·9 cubic feet or 772·5 gallons. The total cost of the alterations amounts to £39 10*s*. In the eight-wheeled engines the capacity of the coal space was inadequate; and here therefore a separate tank had to be resorted to, which is placed above the tender tanks, as shown in Plate 9, and has a capacity

of 227·3 cubic feet or 1417 gallons. This arrangement is of course the more expensive of the two, making the total cost of alteration amount to £76 18*s*., or nearly twice as much as in the other engine.

Results of Working.—In Table XI and the corresponding diagrams, Figs. 52 and 53, Plate 18, are clearly shown both tabularly and graphically for six-wheel coupled 36-ton goods locomotives the comparative consumption and cost of fuel per engine-mile over a whole year when burning coal only and petroleum refuse only. A corresponding comparison for eight-wheel coupled 48-ton goods locomotives is shown in Table XII and diagrams Figs. 54 and 55, Plate 18. In 1882 coal only was used, of which 63 per cent. was anthracite and 37 per cent. bituminous; whereas in 1887 all the fuel used was petroleum refuse. The tables and diagrams show for both fuels alike the whole service of each class of locomotive, including train haulage, shunting, running without train, and standing in reserve under steam; discrepancies therefore cannot occur. Moreover these results include the effects of good bad and indifferent firing; they consequently show broad averages, which the author considers can be thoroughly relied upon. Besides the separate monthly statements, a summary of the year's working is given at the bottom of each table, which may be taken as very conclusive. In the six-wheeled engines the average cost of fuel per engine-mile is seen from Table XI to have been reduced from 7·64 pence for coal in 1882 down to 4·43 pence for petroleum refuse in 1887, being a reduction of 42 per cent.; while from Table XII it is seen that in the eight-wheeled engines the reduction was from 11·02 pence for coal in 1882 down to 5·84 pence for petroleum refuse in 1887, which is a saving of 47 per cent. The yearly cost, as summarised for each class of engine, must of course vary with the fluctuations in the cost of the petroleum refuse per ton. In 1885 the cost per ton in the barges at Tsaritsin on the Volga was 17*s.* 5*d.*, whereas at the end of 1887 it had fallen to 13*s.* 7*d.* The cost per engine-mile, given in Tables XI and XII, includes cost of transport, storage, superintendence, and depreciation of tanks, pumps, pipes &c.

From Table XI it will be seen that the equivalent of 100 tons of coal in 1882 in the six-wheeled engines was 55 tons of petroleum refuse in 1887, being a reduction of 45 per cent. in weight of fuel; while from Table XII the saving of weight in the eight-wheeled engines came up to 49 per cent. in 1887, that is 51 tons of petroleum refuse were equivalent to 100 tons of coal. These broad comparisons, extending over a whole year's running with each fuel, include of course all the ordinary fluctuations both in working and in condition of engines. With a locomotive in first-class order and in the hands of a skilful driver, the author has no hesitation in saying that 50 tons of petroleum refuse are equal to 100 tons of first-class coal, while in special trials this ratio has even been exceeded. But from special trials it would not be safe to draw conclusions regarding ordinary working; and therefore the broad comparison presented by Tables XI and XII is to be preferred as most authentic.

In Table XIII is given the comparative consumption of anthracite and of petroleum refuse per train-mile and per ton-mile in the six-wheeled and eight-wheeled goods locomotives, as ascertained in special trials made respectively in 1883 and 1884. The trials of the six-wheeled engines extended over one double journey with each fuel on the section of line between Tsaritsin and Archeda, a distance of 97 miles, of which the profile is shown in Fig. 50, Plate 17, with the gradients marked thereon. The result is seen to be that the equivalent of 100 tons of anthracite was 48 tons of petroleum refuse, being a reduction of 52 per cent. in weight of fuel. The trials of the eight-wheeled engines were made on the 69 miles length of line between Borisoglebsk and Filonoff, of which the profile is shown in Fig. 51 with the gradients marked. The coal-burning engine ran six double journeys and the petroleum engine twenty-four, with the result per ton-mile that 45 tons of petroleum refuse were equivalent to 100 tons of anthracite, being a reduction of 55 per cent. in weight of fuel per ton-mile. These comparisons were made with the greatest care possible, with engines in first-class order, thus showing the highest efficiency possible in locomotive practice; the results must therefore be looked upon as exceptional.

In order to present in another form the comparative cost of working with coal and with petroleum, the cost of fuel is given in Table XIV, and in diagram Fig. 56, Plate 19, per thousand axle-miles of trucks wagons or carriages (not locomotives), whether loaded or unloaded, extending over a period of thirteen years from 1876 to 1888 inclusive. During the first seven years to 1882 coal alone was the fuel used; in 1883 about 15 per cent. of the work was done with petroleum refuse, and in 1884 about 62 per cent.; while in 1885 to 1888 petroleum refuse was the sole fuel used. It will be seen that from 17*s.* in 1882, the last year in which coal was used alone, the cost fell to 8*s.* in 1888, being a saving of 53 per cent. In 1888 there was fully one month more of winter weather, making the cost of fuel slightly higher than in 1887.

The entire working cost of the locomotive department for the same period of thirteen years from 1876 to 1888 inclusive, per thousand axle-miles of trucks wagons or carriages (not locomotives), whether loaded or unloaded, is given in Table XV and diagram Plate 20. The item of fuel, which in Table XIV consisted of that burnt in the locomotives only, here includes also that burnt in the engine sheds and drivers' rooms, as well as expenses of management of the fuel department; it is consequently rather higher than shown in Table XIV. At the foot of Table XV are added the total axle-miles in each year, and the total working cost. It will be seen that from 39·13 shillings in 1882, the last year in which coal was used alone, the working cost fell to 22·13 shillings in 1888, being a saving of 43 per cent. Consequently, although the total axle-miles rose from 97,927,740 in 1882 to 136,909,500 in 1888, the total working cost was brought down from £191,442 in 1882 to £151,029 in 1888, being a reduction of £40,413 in the locomotive department of the railway.

Irrespective of cost, the comparative consumption of fuel is shown in Table XVI and the corresponding diagram Fig. 57, Plate 19, per thousand axle-miles of trucks wagons and carriages (not locomotives) during the six years 1882 to 1887 on the Grazi and Tsaritsin Railway, using in 1882 coal alone and from 1885 petroleum alone, and on the two neighbouring lines which meet at Grazi and are still continuing to use coal alone, namely the Kosloff

Voronesh and Rostoff Railway and the Orel and Grazi Railway. Irrespective of cost, it will be noticed that in 1882, the last year in which coal alone was used on the Grazi and Tsaritsin Railway, when the proportions were 63·2 per cent. of anthracite and 36·8 per cent. bituminous, the consumption was 0·401 ton, the proportion of unremunerative engine-miles being 30 per cent.; while in 1887, using petroleum refuse alone, the consumption for the same work was only half as much, namely 0·200 ton, with 26 per cent. of unremunerative engine-miles. The other two railways have been annually reducing their coal consumption by using more anthracite and less bituminous coal, besides reducing their unremunerative engine-mileage, the proportion of which is least on the Orel and Grazi Railway on account of this line forming a cross-country connecting link between two main through lines. The table and diagram show a broad average comparison between the consumption of petroleum refuse and that of coal on neighbouring lines. On the Tsaritsin line there is much shunting at the harbours on the Volga and the Don, in connection with the enormous wood traffic from the Volga to the Don, and thence to the Sea of Azoff and the Black Sea.

Effect of Petroleum Fuel on Boilers.—Several slight casualties which took place when the author's coal-burning locomotives were first fired with petroleum refuse led him to imagine that in consequence of the heat being so intense the cost for incessant repairs would be even greater than with coal. For instance, nuts screwed on the lower ends of the fire-box roof stay-bolts dropped off, owing to the very intense heat. In order to ensure perfect safety, these bolts are now made with solid heads, not welded on, but forged solid by upsetting the end of the bolt in forging. In Fig. 26, Plate 10, are shown the Belpaire bolts so forged with a solid head, as used in the author's eight-wheeled locomotives. Six years' experience has shown that since the introduction of petroleum refuse as fuel the cost of repairs has been considerably diminished from what it was previously when firing with anthracite, which is particularly destructive to the fire-boxes and tube ends. In Table

XIV and in the corresponding diagram Fig. 56, Plate 19, is shown the comparative cost of engine and tender repairs per thousand axle-miles of trucks wagons or carriages (not locomotives) during the thirteen years 1876 to 1888, forming part of Table XV and Plate 20; and it is seen that in 1882, the last year in which coal was used alone, the repairs cost 4·7 shillings, while in 1888, when burning wholly petroleum refuse, the cost had fallen to 2·4 shillings, being a reduction of 48 per cent. The petroleum flame produces in reality no more detrimental effect on the fire-box and tubes than a wood flame, owing to the protection afforded to the more important parts by the fire-brick lining. Moreover petroleum refuse does not contain any sulphur, which is so prevalent in all coals and so injurious to the metal of the fire-box and tubes.

Plating up of Fire-door.—Since the discussion of his former paper the author has availed himself of a suggestion then made by Mr. Joseph Tomlinson (Proceedings 1884, page 299) that in a locomotive burning petroleum there need be no firing door whatever to the furnace. Although adequate reasons were given at the time (page 322) why it would not then have been expedient to do away with the firing door, Figs. 38 and 39, Plate 13, yet, now that petroleum refuse promises to be the fuel of the future for many years to come, the author has already plated up the firing door both inside and outside, Figs. 40 and 41, thus adding $2\frac{1}{2}$ square feet of very effective heating surface to the fire-box, and obviating all possibility of leakage at the fire-door ring, and making a neat job altogether. A sight-hole is made through a hollow stay-bolt S; and a manhole in the bottom of the ashpan affords access to the interior of the fire-box for repairs and inspection. Many fire-boxes are now made without any firing door, as shown in Fig. 42, Plate 13.

Verderber Boiler.—With regard to the further suggestion made by Mr. Tomlinson and Mr. Tomkins (Proceedings 1884, pages 299 and 314) that a more special construction of boiler should be employed for petroleum firing, the author is of opinion that it would be difficult to mature a better design than the present locomotive

boiler for working at high pressures and giving great power in a comparatively small space. By way of experiment however, without discarding the old locomotive boilers, the author has lately adopted a construction of boiler devoid of any internal fire-box, which was first introduced by Mr. Stephan Verderber in 1879 on the Hungarian State Railways. A somewhat similar arrangement had been introduced in 1827 on the Saint-Etienne and Lyons Railway in France by Mr. Marc Seguin.

The Verderber boiler, as shown in Figs. 27 and 28, Plate 10, consists of a cylindrical shell, forming the boiler proper, and of an external fire-box or furnace lined inside with fire-brick; the fire-box is completely separated from the boiler proper, and the only way in which it contributes directly to the evaporation of the water is by its radiation of heat to the tube-plate. The fire-brick lining causes the whole fire-box surface to partake of the advantages of the fire-brick arch already in general use in coal-burning locomotives. The results of trials made with two locomotives, which differed only in one of them having the fire-box thus modified, showed that there was an appreciable economy with the altered fire-box, and that with the same combustion of coal the blast orifice must be closed more with the fire-brick furnace, because the temperature in the furnace is some 630° Fahr. higher, and consequently the volume of the gases passing through the tubes is increased nearly 35 per cent. The sediment ordinarily settling upon the fire-box plates here settles as rapidly upon the back ends of the tubes for one-third of their length; and to facilitate its removal, some of the bottom tubes are omitted, and a mud-hole M is provided in the boiler near the fire-box. As the water space in the Verderber boiler is considerably diminished by the removal of the internal fire-box, it is requisite, in order to maintain the same rate of evaporation, that the feed should be effected continuously by an injector adjusted for the mean rate of evaporation, so as to prevent too sudden fluctuations of water level. A lagging of 20 inches thickness of slag-wool outside the fire-box shell keeps the heat in sufficiently to allow of holding the hand upon it. The fire-brick furnace has run five months without any shaking, the boiler making steam as usual. When in the shops for repairs, the cost of altering

an engine to this plan would be not more than £50; whereas to renew a copper fire-box in a large locomotive, with its multitude of stays and roof bolts and rivets, costs £250, or five times as much. The large extent of the fire-brick lining, while preventing damage to the boiler plates, tends also to ensure the complete combustion of the liquid fuel, and to maintain a regular temperature under irregularity of firing. The loss of heat by radiation from the furnace is decreased, in consequence of the fire-brick lining, and of the fire-door not having to be opened for firing. The increase in the number of tubes that can be got into the boiler, along with the extra heating surface due to the lengthening of the whole of the tubes by 2 feet $1\frac{1}{2}$ inches at the fire-box end, more than compensates for the loss of fire-box surface, although the latter surface is admittedly more profitable than that of the tubes for evaporation per square foot, as fully demonstrated by the experiments recorded by M. Couche,* which are presented in a condensed form in Plate 21.

Having occasion to renew some worn out copper fire-boxes, the author adopted a modification of the Verderber furnace for two locomotives, goods and passenger, fired with petroleum refuse, which have now been running over two years. From his own observations with these two locomotives he would have no hesitation in using the plan for all his boilers, as there is much about it which in his opinion recommends it for firing with liquid fuel. In Plate 11 is shown the furnace of the goods engine, and in Plate 12 that of the passenger engine. It will be seen that the brick arch forming the roof of the Verderber furnace is here replaced by a crown sheet, which not only increases the water space of the boiler and adds some very useful heating surface, but also appears to the author to be indispensable for the two following reasons. Firstly, there could be no guarantee that the brick roof of the Verderber furnace would not come down some time while running, and so bring the train to a premature stop on the line. Secondly, the crown sheet having water on the top of it carries the water level back again to the original back plate of the fire-box, where all the water-gauge fittings are ordinarily mounted. The consumption of fuel per train-mile with

* Permanent Way, Rolling Stock, and Working of Railways; by Ch. Couche. Vol. 3.

these fire-brick furnaces is no more than with ordinary locomotive boilers having internal fire-boxes; and the author is indeed disposed to conclude that there is a decided economy in their favour on this score. In comparison with engines of the same class but with ordinary fire-boxes, the mean of several trials made with the Verderber fire-boxes gave an economy of 8 per cent. in the passenger engine and of 4 per cent. in the goods engine, in saving of fuel per train-mile; for greater satisfaction these trials are to be continued for one year in the regular train service (see pp. 82–3). But the greatest advantages of the fire-brick furnaces are the reduction in first cost and in cost of maintenance, and the shorter time the engines have to stand in the repairing shop, inasmuch as the boiler repairs amount simply to changing the tubes and renewing the brick lining of the furnace. Even with coal, with which Mr. Verderber's experiments were made, the evaporation attained per pound of fuel was equal to that with the ordinary fire-box. The object of his plan however was not to effect economy in fuel, but rather to obviate the incessant damage to fire-boxes and the consequent stoppages, which were caused by rapid incrustration in the water spaces surrounding the fire-box, from the very bad feed-water he had to contend with; and this object he fully attained. The six-wheel coupled goods locomotive, of which the furnace is shown in Plate 11, was altered in August 1885, and has been running ever since; it had previously, when burning coal, 151 tubes of $2\frac{1}{8}$ inches diameter, and a total heating surface of 1248 square feet, including 82 square feet in the fire-box; it has now 157 tubes of the same diameter, and 2 feet $1\frac{1}{2}$ inches longer, which with 13 square feet in the fire-box roof give a total heating surface of 1410 square feet, or an increase of 162 square feet. As shown in Fig. 30 the fire-brick lining is secured to the fire-box shell by means of vertical angle-irons riveted to the shell plates and imbedded in the fire-brick.

A special form of boiler for petroleum firing, designed by Mr. Paschinin, which may be described as something like a Cornish boiler having a larger internal fire-box with a flue extending thence along the bottom of the barrel to the smoke-box, and with tubes added above the flue, appeared to the author at the time of its

suggestion to involve the serious structural defect that the expansion and contraction of the long flue, which would be exposed to much greater heat than any other part, must tend to tear its end connections to pieces in the absence of any arrangement for taking up the expansion. This proved to be the case with a boiler so constructed for the Transcaucasian Railway at the Kolomna Locomotive Works near Moscow. Besides presenting so dangerous a defect, the few trials made with the engine showed that this boiler consumed more fuel than an ordinary boiler of the same class of engine; and it is therefore looked upon as a complete failure, at least for locomotive purposes.

Blower for Air Supply to Furnace.—The suggestion made by the late Mr. Crampton (Proceedings 1884, page 307) that the air should be absolutely injected with the steam and oil, and mixed with them in the exact proportion required for perfect combustion, has been carried out by the author by combining the spray injector with an induction air-blower, as shown in Fig. 37, Plate 13. The spray injector itself is the same as that ordinarily used, with simply the addition of three concentric nozzles, fixed one in front of another, so that the steam jet passing through them draws along with it a supply of air entering through the annular spaces between the cones. In a less developed form this idea had indeed already been adopted in his first and subsequent practice; but with the blower shown in Fig. 37 sufficient air is supplied for a full fire, even if the ashpan doors are closed altogether. This blower was fitted to a six-wheel compound goods engine which had been altered from an ordinary locomotive during the summer of 1887. It is more especially necessary in a compound locomotive, because the blast in that case is very soft and makes only two beats per revolution instead of four, whence some difficulty was encountered in getting the adequate supply of air into the fire-box by means merely of the draught produced by the exhaust. The blower was therefore resorted to, whereby the difficulty was fully solved. As however no appreciable advantage in fuel economy was found to result from its use, while at the same time it was terribly noisy in working, it has now been discarded.

Compressed Air for Spray Injector.—Experiments were also made on the use of compressed air instead of steam for the spray injector. An air pump was fitted on the front cylinder-cover on the right-hand side of a goods locomotive, so as to be under the driver's eyes; it was worked by the tail end of the piston-rod, which passed through the cover and was fitted with a piston 6 inches diameter, making of course the same stroke as the steam piston. The air pump was single-acting, and compressed the air up to six atmospheres into a receiver provided with a spring safety-valve. Thence the compressed air was conducted through a coil of 2-inch piping inside the smoke-box, thus picking up a good deal of waste heat, which it then returned through the spray injector into the fire-box. With this arrangement the engine ran two months, but no appreciable reduction in consumption of fuel was noticed, whilst a good deal of the engine power was exerted in compressing the air; and the air pump being only on one side, its working tended to give the engine a lurch sideways, which was noticed when running slow. A more serious fault however of the arrangement was that, when the engine was running up an incline, and the speed was consequently slow, as low indeed as eight miles per hour, too little air was then pumped into the receiver, although it was just at this time that a strong fire was required for supplying the extra quantity of steam needed up the incline; whereas in running down an incline the opposite was the case, too much air being compressed when none at all was required, as the fire was stopped altogether and the brakes were applied. Even if this twofold objection should be obviated, the author is of opinion, from what could be observed during the two months' trial, that the complication and cost of the extra gear would not be recouped by a sufficient economy in fuel consumption. The idea has therefore been completely abandoned, at least for locomotives, the boiler steam being found the most convenient agent for injecting the spray of petroleum refuse into the furnace.

Evaporative Value of Petroleum Fuel.—In Table XVII, which is a slightly modified reproduction of one given in the former paper (Proceedings 1884, page 274), is shown the theoretical evaporative

value of petroleum fuel in comparison with that of coal, as determined by Messrs. Favre and Silbermann. At an effective pressure of $8\frac{1}{2}$ atm. or 125 lbs. per square inch, the highest evaporative duty of the petroleum refuse used in the author's locomotives on the Grazi and Tsaritsin Railway has been 14 lbs. of water per lb. of fuel; in comparison with the theoretical evaporative value given in Table XVII of 17·1 lbs, the actual efficiency of the fuel is therefore nearly 82 per cent. The only way of increasing the efficiency of liquid fuel appears to the author to be to make it into crude gas and work it on the regenerative principle; but such a plan, however successful it might be in metallurgical furnaces or indeed for stationary boilers, is quite inapplicable to locomotives.

Copper Tubes.—By way of experiment, with a view to raising the efficiency of petroleum fuel, the author fitted two locomotive boilers with solid-drawn copper tubes of 2 millimetres (0·079 inch) thickness and $2\frac{1}{8}$ inches diameter, having thick copper ferrules brazed on the ends next the fire. With these tubes steam is made very readily, so much so that the blast-pipe had to be increased in area. As these engines have only recently commenced running, the economy in fuel has not yet been ascertained; but the author has no doubt the copper tubes will produce an appreciable economy, and he will be happy to communicate the results as soon as they are fully known. (See discussion, page 79.)

Scrap Welding Furnaces.—In Figs. 43 and 44, Plates 14 and 15, are shown a longitudinal section and end elevation of the larger of two scrap-welding furnaces, fired with petroleum refuse, which have now been in daily use for about three years at the Borisoglebsk works, and are giving perfect satisfaction. The body of the furnace is of the usual reverberatory form, and in place of a fire-grate it has three air spray injectors at the firing end, which are placed almost on a level with the bridge. Through these three blast injectors the whole of the air required for combustion is supplied. As no unconsumable particles exist in the fuel, no ash pit is required, and no cleaning is necessary during working; hence the furnace can work continuously

so long as the roof does not get burnt out. It also slags very freely, thus proving that quite sufficient heat is available for all practical purposes. The blast used is cold, and from the ordinary smithy main. It was at one time contemplated to heat the air by the waste heat from the furnace itself; but being short of boiler power the author had to utilise the waste heat from both these welding furnaces for heating a large elephant boiler erected close by, which now supplies almost sufficient steam for the steam-hammers and rolling mill. The petroleum reservoir R is placed right above the larger furnace, in order that during winter the refuse may be kept in a liquid state by the heat radiating from the furnace; it supplies both furnaces through a separate pipe to each. Besides a main cock M on the pipe to each furnace, there are also three half-inch cocks C C C for regulating minutely the supply of fuel to the three spray injectors of the larger furnace. The liquid trickling from these cocks spreads into a thin film upon an inclined shoot cast in one piece with the blast pipe, which terminates at the furnace end in a wide flat tuyere, as shown in Figs. 45 to 47, Plate 15. The blast issuing from this broad rectangular orifice carries with it in the form of spray the thin flat film of petroleum dropping from the orifice above; and the jet striking against the low bridge, half a brick high, produces a thorough mixture of air and gas, the proportions of which are so accurately regulated that a perfect white welding heat is maintained in the furnace without any smoke being emitted. The larger furnace has three blast injectors, while the smaller requires only two. The same construction of blast injector is now used also in the tire fires, in place of the circular tuyere nozzles previously employed (Proceedings 1884, Plate 59).

The great simplicity of the appliances for thoroughly utilising liquid fuel for metallurgical purposes, even for forgings of the largest size, commends itself in any country where this fuel can be had at a cheap rate. As no trace of sulphur exists in petroleum refuse, no deteriorating effect can take place upon the iron. With coal, especially Russian bituminous from the Donetz coal basin in South Russia which is rich in sulphur, it is impossible to get iron of first-rate quality. In tests made on iron rolled from poor unwashed

scrap welded with liquid fuel it was invariably found that a very homogeneous ductile metal of high quality was produced. As compared with coal a saving is effected of 40 per cent. in weight of fuel, besides the output being considerably increased.

On Monday mornings $3\frac{1}{2}$ hours are required for heating the larger furnace up to a white heat, with a total consumption of 540 lbs. of petroleum refuse. On all other days in the week $1\frac{3}{4}$ hours are required, with a consumption of 125 lbs. To make one ton of blooms in the larger furnace alone from small unwashed scrap three times welded requires a consumption of 17 cwts. of petroleum, with a loss of iron of from 18 to 20 per cent. In practice however both furnaces are at work at the same time, and the blooms are passed from one to the other when being hammered, thus keeping the heat up in blooms and furnaces, and reducing the consumption of petroleum to 13 cwts. per ton of rolled bars of light sections.

Brass Melting Fires.—In Plate 16 are shown a plan and vertical section of the two brass-melting furnaces using liquid fuel, which the author has also had in daily work now about three years with entire satisfaction. The same fires were formerly used with coke as fuel; they are of the well-known make having drop bottoms, which however are not now used, as no unconsumed residue remains in the furnace. The same blast tuyere is used here as in the welding furnaces and tire fires; one is quite sufficient for each brass fire, and is set tangentially to it, as shown in the plan, Fig. 48, thereby giving a whirling motion to the flame, which coming in contact with the white-hot fire-brick lining ensures complete combustion of all the particles it contains. The blast used is cold, and supplied from an ordinary fan. Besides occasioning a much cleaner foundry, free from sulphurous fumes, the adoption of petroleum in place of coke has resulted in a sensible economy in fuel, as well as a saving of time in melting. The results are as follows:—with coke, 40 lbs. of brass castings were made with 35 lbs. of fuel and 10 per cent. loss of metal; while with petroleum refuse 40 lbs. of brass castings are made with 18 lbs. of fuel and only 6 to 7 per cent. loss of metal, and with 25 per cent. saving in time.

It is of course quite possible that a better arrangement could be made for this purpose; but, as in the case of the locomotives, the plan here shown is the simplest and most direct way of applying the liquid fuel under existing circumstances, and the author has been so satisfied with the results that he has not seen any necessity for further experimenting.

Lubrication.—The petroleum refuse burnt in the locomotives is also found to make an excellent lubricant, and for some years past nothing else has been used for the wagons and tenders, thus reducing expenditure considerably. The only thing necessary is to get it pure, without sand or grit; and fortunately this can readily be managed by skimming the cream off the top of the reservoirs in summer after they have stood some time for settling. In this way a very pure oil is obtained for lubrication, although black in colour.

From laboratory experiments made at Borisoglebsk on the comparative qualities of petroleum refuse as a lubricant under varying conditions of temperature, it was found that in summer it can be used by itself as a lubricant for carriages, trucks, and tenders, and also for all pumping engines and other rough machinery. As cold sets in, it is indispensable to add to the petroleum refuse from 30 to 50 per cent. of solar oil, a mineral oil which is one of the products of distillation from crude petroleum and has a specific gravity of 0·860 to 0·870 and a flashing point of 100° centigrade or 212° Fahr. As petroleum refuse by itself becomes in cold weather too thick to rise through a wick by capillary attraction, solar oil is added in proportion to the coldness of the atmosphere, so as to preserve the necessary fluidity.

In place of the usual plan of testing the value of a lubricating oil by measuring the external friction of rubbing surfaces lubricated therewith, the novel idea occurred to Professor N. Petroff, professor of mechanics in the Technological Institute, St. Petersburg, of measuring the internal friction among the molecules of the oil itself. For this purpose a sample of the oil to be measured is passed with a definite pressure through a glass tube of $1\frac{1}{2}$ mm. = 0·06 inch bore and 505 mm. = 20 inches length, which is immersed in a water

bath kept at various temperatures; and the friction is determined by the time required for passing a measured quantity of oil through the tube. The results, expressed originally in milligrams of pressure per square millimetre of bore of the glass tube, are represented by the curves plotted in the diagram, Fig. 58, Plate 19, in which the scale of pressure has been converted to hundredths of a pound per square inch of bore. As a standard for comparison the friction of rape oil is taken, which is represented by the curve RR. Petroleum refuse used by itself, without admixture, gives the two curves A and B: of which A represents the petroleum refuse used by the author in February 1886, having a specific gravity of 0·904 at 20° centigrade or 68° Fahr.; and B represents that used in July 1885, having a specific gravity of 0·895 at the same temperature. The three curves C D E correspond respectively with admixtures of 30, 40, and 50 per cent. of solar oil; the two higher percentages are employed in very cold weather, while 30 per cent. is the admixture used in spring and autumn. At temperatures of from 40° to 45° centigrade or 104° to 113° Fahr. it will be noticed that the friction of petroleum refuse by itself in the line B B approaches pretty near that of rape oil in the line R R; while the addition of 30 per cent. of solar oil, as shown by the line C C, reduces the friction to the same as with rape oil at the above temperature, thus rendering the train resistance consequently the same. Similarly the lines D D and E E show respectively the same friction as rape oil at the lower temperatures of about 32° and 18° centigrade, or 90° and 64° Fahr.

Now that petroleum seems destined to occupy a prominent place in India as well as in many other parts of the world, these results in regard to its value as a lubricant can hardly fail to be of interest to engineers, irrespective of its use as a fuel.

Equivalent Russian and English Measures.

1 sajene = 7 feet. 500 sajenes = 1 verst = 0·6629 mile.

1 pound = 0·90285 lb. 40 pounds = 1 pood = 36·114 lbs. 62·0257 poods = 1 ton.

1 copeck = 0·24 penny. 100 copecks = 1 rouble = 24 pence.

1 copeck per pood = 14·886 pence per ton.

TABLE X.

Cost of Alterations for Petroleum Firing in Six-wheel and Eight-wheel Coupled Goods Locomotives on the Grazi and Tsaritsin Railway of 5 feet gauge.

SPRAY INJECTOR AND CONNECTIONS.	Six-wheel and Eight-wheel Engines. £ s. d.	
Spray Injector	2 5 0	
Indicator to Injector	11 0	
Gas pipe, 2 inches diameter	6 0	
Copper pipe, 2 inches diameter	8 0	
Gas pipe ¾ inch diameter, 23 lbs.	7 11	
Worm and other copper pipes, 61 lbs.	4 0 0	
Wire netting for strainers	3 2	
Iron fittings, various, 45 lbs.	1 7 6	
Brass cocks, various	1 0 0	
Elastic hose with brass end-sockets	8 0	
Brass mouthpiece on injector, 7 lbs.	6 3	
Steam valve, ¾ inch	4 0	
Two triple connections for steam pipes, 7 lbs.	6 2	
Workmanship	3 14 0	
Total cost of Engine fittings	**15 7 0**	
BRICKWORK IN FIRE-BOX.	Six-wheel Engine. £ s. d.	Eight-wheel Engine. £ s. d.
Fire-bricks from Glenboig Works, 350 and 400, at 20s. per 100	3 10 0	4 0 0
Fire-clay, two barrels = 400 lbs.	2 5 0	2 5 0
Bricklayer's wages	6 0	6 0
Total cost of Brickwork	**6 1 0**	**6 11 0**
TENDER.		*
Iron plate, 3-16ths inch thick, with angle-irons	13 2 0	55 0 0
Workmanship	5 0 0	
Total cost of Tender alterations	**18 2 0**	**55 0 0**
Total Cost of Engine and Tender alterations	**39 10 0**	**76 18 0**

* The eight-wheel engine has a separate tank added on the top of the tender, Plate 9, thereby increasing the cost so much above that in the six-wheel engine, Plate 8.

TABLE XI.

Consumption and Cost of Coal in 1882, *and of Petroleum Refuse in* 1887, *per Engine-mile, in Six-wheel Coupled 36-ton Goods Locomotives on the Grazi and Tsaritsin Railway.*

See Diagrams, Plate 18, *Figs.* 52 *and* 53.

Months.	COAL in 1882, including wood for lighting up.						PETROLEUM REFUSE in 1887.					
	Average Number of Trucks in train. *	Total Train-miles.	Total Truck-miles. *	Total Engine-miles.	Average per Engine-mile.		Average Number of Trucks in train. *	Total Train-miles.	Total Truck-miles. *	Total Engine-miles.	Average per Engine-mile.	
					Con-sump-tion.	Cost.					Con-sump-tion.	Cost.
	No.				Lbs.	Pence.	No.				Lbs.	Pence.
January .	21·32	42,112	897,821	78,214	60·79	8·70	21·29	81,982	1,876,286	115,486	33·62	4·81
February .	27·47	20,150	560,152	43,158	53·54	7·31	21·18	61,716	1,324,729	87,987	35·58	5·10
March . .	26·52	12,415	329,250	27,752	51·21	7·11	21·60	59,022	1,269,660	92,139	33·73	4·76
April . .	28·59	35,117	1,004,119	57,614	52·29	7·22	25·46	79,763	2,030,993	112,808	32·04	4·58
May . .	31·90	70,206	2,241,277	111,181	55·60	7·50	26·21	109,621	2,942,454	151,117	30·90	4·42
June . .	30·74	99,002	3,043,845	147,720	55·87	7·85	25·43	100,602	2,556,849	138,015	25·90	3·70
July . .	28·39	93,406	2,652,502	145,232	47·29	6·63	26·14	97,409	2,516,251	137,159	29·16	4·17
August .	27·04	99,951	2,703,476	152,619	48·44	6·43	24·87	97,895	2,434,167	138,222	28·23	4·01
September.	28·93	92,887	2,693,239	143,090	53·88	7·09	23·82	83,972	2,000,509	120,577	28·90	4·15
October .	23·30	109,602	3,101,778	163,443	60·49	8·23	24·01	97,205	2,333,700	131,925	30·75	4·41
November.	21·61	116,029	2,508,388	159,670	62·03	8·50	21·11	94,910	1,995,111	133,288	31·67	4·11
December .	20·04	75,707	1,518,073	112,119	66·39	9·03	21·69	57,648	1,249,949	90,025	28·23	4·62
Means and Totals	26·32	866,584	23,253,920	1,341,782	55·65	**7·64**	23·51	1,024,778	21,560,661	1,450,948	30·72	**4·43**

* Trucks each 16 tons gross weight.

TABLE XII.

Consumption and Cost of Coal in 1882, *and of Petroleum Refuse in* 1887, *per Engine-mile, in Eight-wheel Coupled* 48-*ton Goods Locomotives on the Grazi and Tsaritsin Railway.*

See Diagrams, Plate 18, *Figs.* 51 *and* 55.

Months.	COAL in 1882, including wood for lighting up.						PETROLEUM REFUSE in 1887.					
	Average Number of Trucks in train. *	Total Train-miles.	Total Truck-miles. *	Total Engine-miles.	Average per Engine-mile.		Average Number of Trucks in train. *	Total Train-miles.	Total Truck-miles. *	Total Engine-miles.	Average per Engine-mile.	
					Con-sump-tion.	**Cost.**					Con-sump-tion.	**Cost.**
	No.				Lbs.	Pence.	No.				Lbs.	Pence.
January .	33·82	38,271	1,294,696	45,271	95·97	13·71	36·33	71,544	2,563,434	89,001	45·48	6·51
February .	34·21	31,674	1,082,921	37,414	83·17	11·76	36·92	51,444	2,009,996	68,294	46·16	6·65
March . .	33·41	18,925	632,410	20,881	84·91	12·06	36·57	48,733	1,715,700	62,156	43·84	6·39
April . .	38·14	20,964	850,147	24,293	70·89	9·81	39·59	42,861	1,697,150	51,514	37·10	5·31
May . .	41·24	28,388	1,170,965	33,145	68·58	9·63	41·88	63,153	2,643,036	78,057	36·39	5·21
June . .	40·53	32,643	1,321,835	37,520	70·92	9·98	41·75	58,395	2,713,863	73,821	31·55	5·69
July . .	43·61	23,947	1,045,201	29,749	69·67	9·80	41·16	64,799	2,667,427	79,001	35·58	5·10
August .	39·99	33,123	1,308,731	39,151	69·22	9·30	41·54	75,417	3,132,076	91,693	35·54	5·08
September.	39·54	47,188	1,865,870	56,486	74·06	10·00	41·54	76,988	3,198,009	93,279	39·17	5·60
October .	35·13	59,250	2,080.474	71,141	74·83	10·25	42·28	94,722	4,096,414	115,493	44·25	6·31
November.	36·56	57.818	2,114,172	70,466	89·84	12·52	36·70	75,842	2,783,918	94,320	43·78	6·27
December.	34·00	41,619	1,416,010	52,763	96·94	13·41	35·55	57,672	2,050,568	71,792	46·55	6·03
Means and Totals	37·52	433,780	16,183,438	518,313	79·08	**11·02**	39·32	754,870	31,721,621	971,421	40·47	**5·84**

* Trucks each 16 tons gross weight.

TABLE XIII.

Comparative Consumption of Anthracite and of Petroleum Refuse, per Train-mile and per Ton-mile, in Six wheel and Eight-wheel Coupled Goods Locomotives on the Grazi and Tsaritsin Railway.

Coupled Goods Locomotive.	Section of line. *Plate* 17.	Date of trials.	FUEL.	Gross Weight of Train, exclusive of Engine and Tender.	Total Train-miles.	Total Ton-miles.	CONSUMPTION OF FUEL, including wood for lighting-up* when burning coal.		
							Total.	Per Train-mile.	Per Ton-mile.
Six-wheel, 36 tons adhesive weight.	*Fig.* 50. Between Tsaritsin and Archeda, 97 miles.	1883. July	Anthracite	Tons. 480	194	93,120	Tons. 5·709	Lbs. 65·92	Lb. 0·1373
		July	*Petroleum Refuse*	480	194	93,120	2·725	**31·46**	**0·0655**
Eight-wheel, 48 tons adhesive weight.	*Fig.* 51. Between Borisoglebsk and Filonoff, 69 miles.	1884. May	Anthracite	620	410	251,200	14·53	79·38	0·1280
		May and June	*Petroleum Refuse*	706	1,639	1,157,131	29·45	**40·25**	**0·0570**

* When burning coal, the wood for lighting-up was converted into its equivalent of coal and added to the total consumption.

TABLE XIV.

Cost of Fuel, and of Engine and Tender Repairs,
per 1000 Axle-miles of trucks wagons or carriages (not locomotives) on the Grazi and Tsaritsin Railway, during thirteen years, 1876 to 1888.

See Diagram, Plate 19, Fig. 56.

Per 1000 Axle-miles of trucks wagons or carriages (not locomotives).	Coal alone.							Petroleum Refuse 15%. Coal 85%.	Petroleum Refuse 62%. Coal 38%.	Petroleum Refuse alone.			
Year	1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	1884.	1885.	1886.	1887.	1888.
Cost of Fuel, . Shillings	18·7	16·5	15·9	17·2	18·9	18·4	17·1	16·5	13·1	9·9	9·0 †	8·033 †	8·087
Repairs of Engines and Tenders } Shillings	6·5	4·5	3·3	5·3 §	7·5 §	5·3	4·7	4·8	4·5	4·1 *	2·7	2·265	2·416 ¶

§ During 1879 and 1880 the expenses of Repairs were somewhat increased by the amalgamation of the Volga Don line with the main line, the rolling stock of the former being in bad condition.

* The considerable cost of Repairs in 1885 was due to change of fire-boxes damaged or worn by coal firing. For 1887 the cost of Repairs is even less than for 1886, as no fire-boxes are now being renewed.

† The mean cost of Petroleum Refuse per ton on the railway was 27*s.* 3*d.* for 1886, and for 1887 was 26*s.* 6½*d.*, which mainly accounts for the reduction in 1887 in cost per 1000 axle-miles. The mean cost on the railway includes all expenses of pumping, storage, and transport; and depreciation of pumps, tanks, and pipes; and also administration.

¶ The cost of Repairs in 1888 included that of altering four engines to the compound system.

TABLE XV (*continued on opposite page*).

Working Cost of Locomotive Department,
per 1000 *Axle-miles of trucks wagons or carriages (not locomotives),*
on the Grazi and Tsaritsin Railway, during thirteen years, 1876 *to* 1888.

See Diagram, Plate 20, Fig. 59.

Plate 20.	Items of Cost.	1876 *	1877 *	1878 *
		Shillings.	Shillings.	Shillings.
AAA	Salaries of Loco. Supt. and Assistants and office management . .	0·516	0·503	0·441
BBB	Wages and Premiums to Enginemen, including shed foremen and men	7·248	5·826	5·654
CCC	Fuel for Engines, engine-sheds, and drivers' rooms, including management . . .	19·081	16·901	16·341
DDD	Lubrication of Engines and all Rolling Stock and machinery . .	1·886	1·291	1·245
EEE	Water and pumping .	1·844	1·590	1·377
FFF	Repairing Shops, management and wages . .	1·981	1·622	1·739
GGG	Cleaning of Rolling Stock	0·575	0·431	0·434
HHH	Renewals and Repairs of Engines and Tenders .	6·493	4·526	3·298
JJJ	Renewals and Repairs of Carriage and Wagon Stock . . .	8·236	6·698	7·318
KKK	Total Cost per 1000 Axle-miles in Shillings .	**47·860**	**39·388**	**37·847**
Total Axle-miles of trucks wagons or carriages		48,406,497	56,320,237	71,889,982
Total Working Cost in pounds .		£115,621	£111,255	£135,941

* In 1876–82 Coal alone was used in the locomotives.

§ In 1885–88 Petroleum Refuse alone. *See page* 62.

(*continued on following page*) TABLE XV.

Working Cost of Locomotive Department,
per 1000 *Axle-miles of trucks wagons or carriages (not locomotives),*
on the Grazi and Tsaritsin Railway, during thirteen years, 1876 *to* 1888.

See Diagram, Plate 20, *Fig.* 59.

1879 *	1880 *	1881 *	1882 *	1883 †	1884 †	*Plate* 20.
Shillings.	Shillings.	Shillings.	Shillings.	Shillings.	Shillings.	
0·366	0·431	0·465	0·422	0·409	0·386	AAA
6·151	6·277	5·493	5·433	5·232	5·068	BBB
17·509	19·137	18·570	17·125	16·626	13·174	CCC
1·417	1·380	1·217	1·191	1·167	1·083	DDD
1·440	1·630	1·209	1·244	1·184	1·292	EEE
2·119	2·386	1·629	1·644	1·792	1·507	FFF
0·519	0·491	0·405	0·392	0·265	0·368	GGG
5·312	7·538	5·291	4·727	4·838	4·544	HHH
9·956	9·446	8·188	6·955	6·664	5·197	JJJ
44·789	**48·716**	**42·467**	**39·133**	**38·177**	**32·619**	KKK
71,958,659	74,413,099	88,151,537	97,927,740	113,579,960	124,461,939	Axle-miles.
£160,969	£181,020	£186,981	£191,412	£216,473	£202,774	Cost.

† In 1883 Petroleum Refuse 15 per cent. and Coal 85 per cent.
† In 1884 „ „ 62 „ „ „ „ 38 „ „

TABLE XV (*concluded from preceding page*).

Working Cost of Locomotive Department,
per 1000 *Axle-miles of trucks wagons or carriages (not locomotives),*
on the Grazi and Tsaritsin Railway, during thirteen years, 1876 *to* 1888.

See Diagram, Plate 20, *Fig.* 59.

Plate 20.	Items of Cost.	1885 §	1886 §	1887 §	1888 §
		Shillings.	Shillings.	Shillings.	Shillings.
AAA	Salaries of Loco. Supt. and Assistants and office management . .	0·403	0·525	0·483	0·453
BBB	Wages and Premiums to Enginemen, including shed foremen and men	4·627	4·790	4·499	4·318
CCC	Fuel for Engines, engine-sheds, and drivers' rooms, including management . . .	10·067	9·084	8·335	8·486
DDD	Lubrication of Engines and all Rolling Stock and machinery . .	0·845	0·702	0·664	0·634
EEE	Water and pumping .	1·063	1·040	0·875	0·755
FFF	Repairing Shops, management and wages . .	1·639	1·736	1·479	1·479
GGG	Cleaning of Rolling Stock	0·234	0·369	0·302	0·332
HHH	Renewals and Repairs of Engines and Tenders .	4·081	2·682	2·265	2·446
JJJ	Renewals and Repairs of Carriage and Wagon Stock . . .	4·383	3·941	3·443	3·231
KKK	Total Cost per 1000 Axle-miles in Shillings .	**27·342**	**24·869**	**22·345**	**22·134**
Total Axle-miles of trucks wagons or carriages		126,569,995	118,900,533	136,420,000	136,909,500
Total Working Cost in pounds .		£173,118	£147,732	£152,278	£151,029

* In 1876–82 Coal alone was used in the locomotives. } *See pages* 60–61.
† In 1883–84 Petroleum Refuse and Coal.
§ In 1885–88 Petroleum Refuse alone was used in the locomotives.

TABLE XVI.

Consumption of Fuel per 1000 *Axle-miles of trucks wagons or carriages (not locomotives) on the Grazi and Tsaritsin Railway, and on two neighbouring railways burning coal alone, during six years,* 1882 *to* 1887.

See Diagram, Plate 19, *Fig.* 57.

Per 1000 Axle-miles.	Grazi and Tsaritsin Railway.						Kosloff Voronesh and Rostoff Railway.						Orel and Grazi Railway.					
Year . . . . :	1882	1883	1884	1885	1886	1887	1882	1883	1884	1885	1886	1887	1882	1883	1884	1885	1886	1887
Consumption of Fuel, Ton	0·401	0·386	0·285	0·214	0·212	0·200	0·491	0·466	0·420	0·387	0·356	0·367	0·416	0·410	0·382	0·362	0·349	0·346
Anthracite, . Per cent.	63·20	41·89	14·10	...	...	...	66·86	77·03	82·82	85·33	91·77	93·21	70·04	70·94	76·56	80·60	87·67	92·93
Bituminous Coal, Per cent.	36·76	42·95	24·28	...	...	...	33·11	22·97	17·18	14·67	8·23	6·79	29·96	29·06	23·44	19·40	12·33	7·07
Petroleum Refuse, Per cent.	0·04	15·16	61·62	100·0	100·0	100·0	...	...	...	...	...	...	...	...	...	...	...	...
Engine-miles unremunerative Per cent.	30·21	25·53	25·76	27·86	32·62	26·09	29·04	28·10	27·06	26·41	20·64	24·05	28·11	28·01	28·21	23·01	21·18	18·32

TABLE XVII.

Theoretical Evaporative Value of Petroleum Fuel and of Coal.

Fuel.	Specific Gravity at 32° Fahr. Water =1·000.	Chemical Composition. Carbon.	Hydrogen.	Oxygen.	Sulphur.	Heating Power. British thermal units.	Theoretical Evaporation. Lbs. of water per lb. of fuel. From and at 212° Fahr.	At $8\frac{1}{2}$ atm. effective pressure.
	S. G.	Per cent.	Per cent.	Per cent.	Per cent.	Units.	Lbs.	Lbs.
Pennsylvanian Heavy Crude Oil	0·886	84·9	13·7	1·4	..	20,736	21·48	17·8
Caucasian Light Crude Oil .	9·884	86·3	13·6	0·1	..	22,027	22·79	18·9
Caucasian Heavy Crude Oil .	0·938	86·6	12·3	1·1	..	20,138	20·85	17·3
Petroleum Refuse . . .	**0·928**	**87·1**	**11·7**	**1·2**	..	**19,832**	**20·53**	**17·1**
Good English Coal, mean of 98 samples . .	1·380	80·0	5·0	8·0	1·25	14,112	14·61	12·16

Discussion.

The CHAIRMAN said the previous paper on this subject by Mr. Urquhart had commanded a great deal of attention all over Europe and America; and several engineers had since gone to Russia on purpose to see what he was doing. Since the present supplementary paper had been prepared, the author had also sent a few additional remarks which would now be read.

Mr. URQUHART, being unable to come to the Meeting, wrote from Russia that, owing to a coal crisis prevailing there ever since last summer, his system of petroleum firing was being adopted on the central railways of Russia, namely: Moscow and Kursk, Moscow and Nishni-Novgorod, Moscow and Brest, Tamboff and Kosloff, Tamboff and Saratoff, and Orel and Grazi. It was also being adopted on the Roumanian railways, and on the Pennsylvania Railroad; and he had received an enquiry from Livorno (Leghorn) for its application to a locomotive there. The system was likewise intended to be tested on board the Russian torpedo boats.

The price of petroleum refuse per ton delivered at Tsaritsin was at the present time $10\frac{1}{2}$ copecks per pood, equivalent at 2*s.* per rouble to 13*s.* per ton. At Nishni-Novgorod on the Volga, which was the main port for Moscow, being by rail only 400 versts = 270 miles east of Moscow, the current price was 15 copecks per pood, or 18*s.* 8*d.* per ton. At these prices it was not surprising to find that all the mills and factories in the vicinity of Moscow and Vladimir had abandoned wood fuel, and altered their furnaces to burn liquid fuel. Apart from steam-boats and railways, there could be no doubt that, in the present scarcity of wood and coal for fuel in Russia, petroleum refuse at these prices came in as a great boon to the manufacturing industries in the Moscow district.

Mr. EDMUND KIMBER represented the Hon. Richard Benjamin Avery of America, who had devoted many years' attention to this subject, and whose inventions were now being tested in a practical

(Mr. Edmund Kimber.)
manner by Messrs. Dübs and Co. of Glasgow. That Mr. Urquhart's paper was a most valuable contribution to practical science might be inferred from the fact that, on the invitation of the Royal Engineering College at Chatham, lectures were now being delivered there on this subject on the suggestion of the government. In Russia great interest was being taken in the matter by the government and military and railway authorities. The subject was indeed one of world-wide importance. It might no doubt be asked how, if petroleum refuse cost 17*s.* a ton at Tsaritsin, it could be of any practical use to engineers in London. But some of the Members were probably aware that a concession had already been granted for the construction of an 8-inch pipe line for petroleum from Baku to Batoum, a distance of 470 miles, for connecting the Caspian Sea with the Black Sea. There was a railway already between those ports; but in the course of a few months another pipe line to avoid the Suram Pass of 50 miles would be completed, and would double the output of petroleum between Baku and Batoum, and ease the transit by rail. Having had occasion to go into calculations as to the cost of transit, he had found that by a tank steamer between Batoum and London it would be practicable to bring petroleum to this country at 10*s.* per ton, while the carriage from Baku to Batoum would be 10*s.* to 15*s.* a ton. The total production of which the wells at Baku were at present capable was about 20,000 tons per day, which he believed was three or four times the present output of all the American oil wells together. But although that was the possible output, the actual output was not more at present than one million tons per annum; and he believed that 60 per cent. or more of the crude petroleum was refuse. Hitherto it had been only the burning oil constituting the remaining 40 per cent. that would pay for the cost of carriage; and it had been necessary to make a great lake of the refuse and sell it at the best price that could be got. It was therefore not surprising that Mr. Urquhart could get it at 17*s.* per ton; and in his own opinion he ought to get it at much less. Of course it paid him, as it would pay everybody in Roumania and Russia, to use it in the way he did; but that seemed to be really a very expensive way of using it, and a

way that no English or American engineer would think of adopting. The output would soon be considerably increased by the pipe line avoiding the Suram Pass, which, although only 6 inches in diameter, would enable the quantity to be at least doubled. The time was therefore coming he thought when Russian oil would be a formidable competitor of American. One firm alone in London had during the present winter received an importation in six weeks of 21,000 tons of Russian burning oil, in seven shipments averaging 3,000 tons each; and at the anticipated rate of increase he was told the price of burning oil would be brought down to $4\frac{1}{2}d.$ per gallon, or £4 10*s.* per ton. At what price then would the refuse used by Mr. Urquhart be brought to London? It would be able to be brought at a profit he thought at £2 per ton; and according to the figures given in the paper it would then pay every industrial enterprise to use it in this country. In his opinion however there was an error in the view expressed in page 49 that "the only way of increasing the efficiency of liquid fuel appears to the author to be to make it into crude gas and work it on the regenerative principle; but such a plan, however successful it might be in metallurgical furnaces or indeed for stationary boilers, is quite inapplicable to locomotives." It might be inapplicable if worked on the regenerative principle; but that was not the most approved principle, and was not the principle which was now being worked out in Scotland and in America. The principle which had been worked out, and he thought successfully, during the last twenty years, consisted in causing the admission, not of crude steam, but of the hydrogen of the steam as hydrogen, mixed with the evaporated oil, into retorts at the sides or bottom of the furnace, so that the mixture might be heated in those retorts before it was admitted into the furnace. Experience showed that, for the purpose of getting the greatest quantity of heat out of the fuel so mixed, it must be made into perfect gas before ignition. Of course it paid the author in Russia to go on in his present way; but the refuse he used could not be bought in England for 17*s.* a ton. At £2 a ton however the fuel might be utilized more economically. It had been found that hydrogen, which could be cheaply made for the purpose, could be added to the evaporated oil to the extent of four volumes of hydrogen

(Mr. Edmund Kimber.)
for fuel, and two volumes of hydrogen for illuminating gas. From the paper he inferred that the author was using about one volume of steam to one volume of evaporated oil, although this was not so stated. If four volumes of steam were used instead, the economy of the process he considered would be increased. That the author had not arrived at perfection seemed to be shown by the wording in page 45, where it was stated that "the large extent of the fire-brick lining tends to ensure the complete combustion of the liquid fuel;" this rather qualified mode of expression seemed to imply that the complete combustion was not absolutely ensured. As to the objection which he believed was sometimes urged against admixture of air with the petroleum refuse, that the heating power would thereby be impaired, he was glad to read in page 50 the great success obtained by the author in the scrap-welding furnace, in which with an air blast a thorough mixture of air and gas was produced, while the proportions were so accurately regulated that a perfect white welding heat was maintained in the furnace without any smoke being emitted.

Professor KENNEDY, Member of Council, pointed out that, while the author claimed to have got already an evaporative efficiency of as much as 82 per cent. out of the petroleum refuse used in his locomotives (page 49), the previous speaker seemed to suggest that somehow or other hydrogen was to be got out of the water (for there was no other source from which it could be got in any large quantity), and then the evaporation was to be multiplied he did not know how many times. But an evaporative efficiency of 82 per cent. left only 18 per cent. to come and go upon, and out of that small margin the chimney gases had to be heated, and more or less waste in other ways had to be allowed for: so that, taking the author's figures as being honestly arrived at, which there was no reason to doubt, there was not a great deal left to economise upon; the limit of economy had already been pretty nearly reached. There were few boilers working at a better evaporative duty than 82 per cent.; at the same time it was clear that nothing like £2 per ton could be afforded here for the fuel, unless an evaporative duty of

more than 100 per cent. could be got out of it. He had checked the figures in Table XVII, and they appeared as far as he could judge to be correct. There was one point however to which he wished to draw attention, because in reality it appeared to make the author's efficiency somewhat higher than he had taken credit for. From the last column of that Table it appeared that under certain conditions, which were no doubt correctly worked out, 17·1 lbs. of water were evaporated per pound of petroleum refuse. It was not stated from what temperature, but apparently some standard had been fixed upon; and instead of the 17·1 lbs. an evaporation of 14 lbs. was obtained, which was 82 per cent. of 17·1 lbs. The petroleum refuse however contained 11·7 per cent. of hydrogen; and he presumed it had been calculated that this was turned into steam and then the steam turned into water, all the latent heat being thus taken into account; for it was only on the assumption of all the latent heat being utilised that the theoretical evaporation of 17·1 lbs. could be arrived at. That was the way in which the theoretical evaporation would naturally be got in the calorimeter, but then the author could not do this in his locomotives; he had to send the combined hydrogen and oxygen up the chimney in the form of steam, and it was consequently impossible in a locomotive or any other boiler to recover the latent heat out of that steam. In a boiler therefore it could not be expected to get so high a theoretical evaporation as 17·1 lbs., but really about 6 per cent. less: so that the comparative efficiency obtained in the author's locomotives, supposing his figures to be accurately arrived at, must be more nearly 87 than 82 per cent., which was a very remarkable result. He only wished that a little more detail could be given of the way in which this evaporation was obtained; the figures he had not the least doubt had been most carefully arrived at, and possibly the author would be able to say what sort of trials had been made, whether long-run trials or trials of a locomotive when it was stationary, or under what circumstances. It was interesting to have a case of such extraordinarily high efficiency; and it would therefore be very valuable to have the details of the method by which the figures were got.

(Professor Kennedy.)

With reference to the statement in page 52 as to the use of crude oil for lubrication, it might be interesting to mention that he remembered speaking to an engine-driver on the Union Pacific Railway, who told him that at one time for an experiment he had been supplied for some weeks with nothing but crude oil which had been treated only by previous heating to about 200°. It was from a natural oil well in Wyoming, and he had used it raw for lubrication in his cylinders, as well as for all other purposes. It was thick, and bad in colour, but was said to be a satisfactory lubricant. That was a corroboration on a small scale of the statement made by the author.

Mr. JAMES HOLDEN said that at Stratford there were gasworks for the production of heavy gas from shale oil for lighting about 1075 carriages on the Great Eastern Railway. At one time there had been a market for the tar from those works; but about three years ago that market failed, and the tar could no longer be so got rid of. A great deal of it had been buried, until the ground had become so saturated that the tar got into the drains, and complaints were received from the surveyor of the borough, who seemed to think it was being deliberately turned into the drains; and it became a serious matter what was to be done with it. Under those circumstances he had been induced, mainly on the suggestion of Mr. Charles Henry Parkes, the chairman of the Great Eastern Railway, to make some experiments with a view of burning the tar; and these had turned out so successfully that he had since been using not only the tar from the shale-oil distillery, but also tar from the Beckton gasworks and green oil, for firing boilers of various descriptions: namely two Cornish boilers, a small vertical boiler, three stationary boilers of the locomotive type, and also three ordinary locomotives, one of which was doing regular shunting work, and another had been working daily for two years past the suburban trains on the Loughton and Enfield branches, while the third was taking the express train from Liverpool Street to Peterborough and Doncaster. So far as the locomotives were concerned, it seemed to him most undesirable, at any rate in the experimental stage, to make any alteration whatever in the fire-box of the engine. He was anxious to burn the liquid fuel if

possible with the fire-box unaltered, and so be able to use either coal or liquid fuel at will, without any delay whatever in changing from one fuel to the other; and in the course of a great number of experiments which he had made, some of Mr. Urquhart's conclusions had been thoroughly verified, as for example the necessity for an accumulator of heat. In his own early experiments he had found that the effluent gases were passing off at so high a temperature as to warp the smoke-box and let the air in round the door. Having got over that objection, he was now working with a 6-inch blast-pipe instead of the $4\frac{1}{2}$-inch blast-pipe previously used, and with very satisfactory results, consuming from 40 to 80 per cent. of liquid fuel, the rest being solid fuel. In the plan adopted on the Great Eastern Railway he was not using liquid fuel alone, but was also keeping a very thin fire of coal on the bars, not more than about three inches thick, just as a basis of combustion, injecting the tar into the fire-box through two tubular stays by means of the small injector which he exhibited, and which was shown in Figs. 61 to 65, Plate 22. The engines used to work at first with a closed damper; but in consequence of the height at which the liquid fuel was injected, namely about 28 inches above the fire-bars, there was a little tendency for the solid fire to go out, owing to the want of a sufficient supply of air. They therefore worked now with the damper a little open, but excluding the greater part of the air from the coal on the grate by covering the bars with a layer of chalk or lime, which settled down very closely and prevented the coal from being burnt too rapidly. A very small amount of coal put on in the morning would last about half the day. In the stationary boilers of the locomotive type nothing was being used as a basis but chalk and a few ashes. The results financially depended of course entirely upon the relative value of coal and of the liquid fuel. With liquid fuel at the price of one penny per gallon, which was about what the tar and the green oil were costing, the economy was sensible but small. He should be happy to afford every facility to any of the Members interested in the subject who might desire to see what was being done at Stratford. The liquid fuel he was using was no doubt much less rich in calorific value than the petroleum refuse which was being

(Mr. James Holden.)

used so satisfactorily by Mr. Urquhart. It seemed to him that it would be very difficult to introduce into this country the method described in the paper, inasmuch as the amount of petroleum refuse in the market was so small that if any large number of engines were fitted up for burning it the price would immediately go up. It therefore seemed desirable to have command of the two markets, and to be able to play the coal off against the liquid fuel, and the liquid fuel against the coal; and this was really the point he had had to keep in view. The most perfect combustion was obtained without any smoke, with very little noise, and without any smell. There had been a great deal of difficulty to get over at first in regard to the smoke; but this had ultimately been surmounted. With the ordinary injector the liquid fuel was admitted through the annular nozzle surrounding the central steam jet, while the induced air supply merely came in as best it could round the central jet of steam and liquid fuel. He had accordingly introduced an entirely independent supply of steam through the hollow ring R in Plate 22, from the front face of which issued through half a dozen small holes separate jets of steam converging towards the nozzle of the injector, so that they crossed the issuing jet of liquid fuel, already partially broken up by the bars in the orifice of the nozzle, and converted it into very fine spray, mixed with a large induced supply of air, which could be varied by the quantity of steam inducing it, so as to get the right amount of air for perfect combustion. In locomotives, and in all similar cases where it was not necessary for the injector to lift the liquid fuel from a lower level, there was also a central jet of air drawn in through the open orifice at the back end; and the same aperture afforded a free passage through the injector for clearing away any temporary obstructions without having to shut off either steam or fuel.

The Chairman asked whether there was any choking up of the orifice of the nozzle.

Mr. Holden replied that there was no difficulty in that respect; the steam blowing through the nozzle kept it always clean. There

was no deposit of soot on the inside of the fire-box; the brick arch used in the fire-box was exactly the same as in an ordinary coal-burning locomotive; and neither in the tubes nor in the fire-box was there any apparent deterioration of the material or any deposit.

The same method of utilising liquid fuel was also being employed at Stratford for a scrap-welding furnace, out of which he was thereby getting 25 per cent. additional heats. In this case the liquid fuel was being used as an auxiliary to ordinary coal; it was blown in by steam through the body of the injector, and currents of air were induced by means of other jets of steam issuing from the ring round the outside of the injector. No difficulty was found in producing a welding heat; in fact it was produced more quickly by the action of the injector. The liquid fuel was also being used in a riveting furnace; and he was arranging to apply it to a regenerative furnace which had hitherto been worked from gas producers of the ordinary kind.

The Chairman asked whether the quality of the iron from the scrap-welding furnace had been improved in consequence of the liquid fuel being free from sulphur.

Mr. Holden replied that he thought so.

Mr. Thomas W. Worsdell, Member of Council, had had no experience in the burning of petroleum in the locomotive or any other boiler; but he had had a very short experience in America of a somewhat similar plan to that referred to by the author in page 49, namely making petroleum into crude gas before burning it in the fire-box of an engine. He had used the ordinary fire-box then existing, without any special preparation except the addition of jets or burners. The experiment however had not been carried on long enough to arrive at any further result than merely running an engine and tender without a train about 12 miles up an incline of 1 in 50 on the Pennsylvania Railroad, in the winter of 1869–1870; he left that railway just about the time when the experiment was laid aside for further consideration, and he did not believe it

(Mr. Thomas W. Worsdell.)
had been further prosecuted in that form. There was no doubt at all that the method shown by the author of having a heavy fire-brick lining to the fire-box or combustion chamber was an important and necessary provision for retaining the heat and causing its diffusion when using a liquid fuel. Judging from the ordinary experience with the burning of oil, there was one question that occurred to himself and was likely to occur to many others: namely, why in the author's modified Verderber furnace, Plates 11 and 12, he had not made use of the heating surface of the fire-box in a better way than he appeared to have done. The back plate seemed to be lined with brick right up to the top, without any water space, and there seemed also to be no water casing round the sides. It appeared to him that a good deal of useful heat must consequently go through the sides and back of the fire-box and be lost. He had been struck with the peculiar form of the fire-box, believing thoroughly in the necessity for the brick lining, but still believing that the boiler would be improved by a water space round the whole of the lining.

Nothing was said in the paper about the flashing point of the oil, which had not always the same flashing point. It occurred to him that carrying a large tank of petroleum on the tender in such immediate proximity to a very hot fire might be likely to cause a liability to explosion. English engineers he thought would be a long time in making up their minds that petroleum could be carried safely in the manner shown by the author.

The consumption of petroleum was stated to be about half that of coal; and the price of the latter might be inferred from Tables XI and XII to have been about 26*s.* per ton in 1882. If the efficiency of petroleum was double that of coal in Russia, it might be taken to be also about double if used in this country; but if, as a previous speaker had said, petroleum could not be got here under £2 a ton, it would be a long time he thought before it would be possible to use it here with any chance of an economical result; for on his own railway, the North Eastern, coal was 6*s.* 6*d.* per ton, and the equivalent to petroleum would therefore be only 13*s.* according to the author, as against 40*s.* the cost just stated of petroleum. Steamboats however, requiring all the cargo capacity

they could get, and saving fuel as much as possible by increased expansion, presented the best opportunity he thought for economy by the use of petroleum, if it were considered suitable in other respects, including safety, which was one of the most important points that had prevented its more extensive use.

Mr. W. Silver Hall enquired respecting Professor Petroff's method of testing oil, how far it was really a fair guide as to the value of oil for lubricating purposes; and he suggested that it would be a simple thing for the Friction Committee to try one or two easy tests in that way with any oils they happened to be using, so as to ascertain how far the results corresponded with those obtained in the ordinary tests. With reference to Mr. Worsdell's suggestion as to the use of petroleum fuel on steamers, it appeared to him that any of the steamers running from the Black Sea would be the best for trying the experiment, because they could get the petroleum on the spot as cheap as possible.

The Chairman pointed out that the burning of petroleum or of coal was a question mainly of cost. In Russia coal might be dear and petroleum cheap; while in England coal might be cheap and petroleum dear. It was stated in the paper (page 39) that the price of the petroleum fuel had fallen to 13*s.* 7*d.* per ton, and that one ton of petroleum could do what it took two tons of coal to do. That gave practically 6*s.* 9½*d.* per ton as the equivalent price for the coal to do the same work at the same cost. In this country coal could be bought in some cases at rather less than that price; and the consequence would be that, if petroleum could be got here for 13*s.* 7*d.* per ton, there would be a hard struggle as to which should win the day. In America petroleum was being used very largely; he had seen it in use in a great many furnaces, and one great advantage connected with its use was that there was no smoke. The author had stated (page 49) that the right thing to do was to make the liquid fuel into crude gas and work it on the regenerative process. This plan had been taken up largely in America at some of the steel-works. All over the world the use of petroleum fuel

(Mr. Edward H. Carbutt.)
was being thoroughly discussed and tried, with the exception that very little had yet been done with it in connection with marine engines. Having asked various marine engineers why this was so, he had always received the answer that it was all very well to use petroleum fuel for a locomotive or stationary boiler, where it had only to be used for a few hours at a time, and where there was then a chance of putting things right in the intervals, but that this was very different from running three or four or five weeks continuously without being able to do anything to the furnace. The Admiralty he knew were looking carefully into all the experiments that had been taking place, and would be delighted if they could use petroleum fuel for their boilers, because it would remove a great many difficulties. The chief hindrance at present was the fear that they could not do with petroleum in a long voyage of five or six weeks what could be done with it in locomotives running only a few hours at a time.

Mr. DANIEL ADAMSON, Vice-President, regarded this question as both a commercial, a scientific, and a practical one, which ought to be thoroughly investigated; and he therefore recommended that the discussion should be adjourned, in order to afford the Members an opportunity of further considering this important subject.

The CHAIRMAN took the opinion of the meeting, which was in favour of closing the discussion. He accordingly proposed a vote of thanks to Mr. Urquhart for the trouble he had taken in preparing this further paper and presenting it to the Institution. The Members he was sure would all wish him success in his experiments, and would be glad to welcome another paper from him at a future meeting.

Mr. URQUHART wrote that, as the Hon. R. B. Avery's inventions were stated by Mr. Kimber (page 65) to be now undergoing a

practical test by Messrs. Dübs and Co., it was to be hoped that at an early date the results would be made known to the engineering profession, with a full description of the appliances.

The enquiry (page 66) as to how, if petroleum refuse costs 17*s.* a ton at Tsaritsin, it can be of any practical use to engineers in London, is met by the consideration that the use of petroleum as fuel is a subject of which the interest is not limited to London, but concerns the British possessions and other countries in many parts of the world, and may therefore well receive the careful attention of mechanical engineers generally. On the completion of the projected pipe line between the Caspian and Black Seas, as well as of the smaller pipe line of about 50 miles over the Suram summit, both of which promise to be accomplished at no very distant date, no doubt Russian petroleum and its various products will then become more plentiful in southern and western Europe, and consequently cheaper; even under these circumstances however the author is not sanguine of petroleum being generally used for fuel, and is of opinion that its use will be limited to special purposes. In Russia it certainly pays the railways and steamboat companies, as well as the manufacturers, to use petroleum refuse even at 50*s.* per ton, for this price is simply equivalent to about 25*s.* per ton for coal; whereas in the Moscow district at the present time coal costs 22 copecks per pood, or over 27*s.* per ton.

As to the remark (pages 66–7) that the method adopted by the author for utilising liquid fuel seems really an expensive way, and one which no English or American engineer would adopt, it is to be regretted that hitherto so few English engineers have had experience with liquid fuel, while in America there have been many futile attempts to solve the problem; and it is only very recently that real progress has been made, owing to the publication of the previous paper and discussion in the Proceedings of this Institution in 1884. The method described in that paper is now being rapidly developed and applied to locomotives as well as other industrial purposes in the United States, wherever the price of petroleum admits of its use with a reasonable margin of economy as compared with the local price of coal.

(Mr. Urquhart.)

Exception is taken in page 67 to the view expressed by the author that the only way of increasing the efficiency of liquid fuel above what has been already attained would be to make it into crude gas and work it on the regenerative principle. There are many boilers now fired by gas, although not on the regenerative principle; and the author's remark had more immediately in view metallurgical furnaces. Even in these however it is not absolutely necessary to work the liquid fuel on the regenerative principle, as is fully shown by experience in the welding of scrap in reverberatory furnaces at Borisoglebsk, as illustrated in the paper (page 49), although no doubt the regenerative system would give a higher efficiency. On this point the author is quite ready to modify his views, as soon as ever adequate proof is forthcoming as to the superior efficacy of the new principle mentioned by Mr. Kimber as now being worked out in Scotland and America. With regard to the expression in page 45 that the large extent of the fire-brick lining tends to ensure the complete combustion of the liquid fuel, what the author desires thereby to convey is that the whole surface of the brickwork is maintained at a white heat, and the gases and air must of necessity come in contact with it; and therefore, instead of going off partially unconsumed as they would do without the hot brickwork, they are perfectly burnt up owing to the high temperature, while at the same time it is possible that more oxygen thus combines with the fuel than would be the case if no brickwork were used. The combustion is really perfect, and entirely free from smoke; and the whole fire is as much under the complete control of the driver or stoker as a domestic gas jet. While it is to be inferred that the new system mentioned in page 67 is at present simply in process of being worked out in Scotland and America, the mode described in the paper of utilising liquid fuel has already been in regular use on the Grazi and Tsaritsin Railway for six years; and is being rapidly developed on other railways in Russia and in other countries, and is giving universal satisfaction. At present therefore in this connection the old maxim may be considered to hold good, that an ounce of fact is better than a ton of conjecture.

Attention has been drawn by Professor Kennedy (page 68) to the evaporative efficiency attained of 82 per cent., which is indeed a high efficiency and may be looked upon as exceptional, at least in locomotive practice, though still not beyond the limits of possibility. The evaporation of $12\frac{1}{4}$ lbs. of water per lb. of petroleum refuse, mentioned in the former paper in 1884 (page 274), was obtained with iron boiler tubes, and may be taken as the ordinary practice in locomotives. In the same year the author had the pleasure of witnessing at Hubner's print works near Moscow a trial made with a stationary boiler of locomotive type, well clad and inside a warm boiler-house and having a natural chimney draught, from which was obtained an evaporation of $13\frac{1}{2}$ lbs. of water per lb. of petroleum. The maximum evaporative duty of 14 lbs., mentioned in page 49 of the present paper, was obtained in the actual working of a six-wheel coupled goods locomotive, having a new set of solid-drawn copper tubes, as mentioned in the same page; the thickness of the tubes did not exceed 2 millimetres (0·079 inch), and probably many of them were thinner. During a run of about 200 miles in summer with a train, the whole weight of water fed out of the tender tank at a temperature of about 59° Fahr. was calculated exactly, and the overflow from the injectors was deducted. The weight of fuel consumed was also calculated exactly, the fire being carefully managed during the trial, so that neither fuel nor air was admitted in excess beyond what was absolutely necessary for maintaining the regular supply of steam in the boiler and enabling the train to keep up to time in the journey. The practical evaporation thus actually obtained, of 14 lbs. of water per lb. of petroleum refuse, the author has not the least doubt can always be realised under careful management with a perfectly clean boiler and copper tubes. Such tubes however are very expensive in the first instance, and are also more liable to leak than iron tubes; so that their higher evaporative efficiency is not sufficient to recoup their extra first cost along with the extra cost of maintenance; and therefore only a few sets had been ordered by way of experiment, which will not be repeated. Now that so high an efficiency as 82 per cent. has been actually realised, in spite of the loss of heat in the gases escaping up the

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chimney, as well as other incidental losses in practice, the subject can scarcely be regarded as being any longer in the merely experimental stage; and although this high result has at present been got at a considerable cost for copper tubes, yet possibly some new construction of boiler may hereafter be devised which will give a still higher boiler efficiency.

In regard to the theoretical evaporation given in the two last columns of Table XVII, it may be explained that the evaporation of 20·5 lbs. of water from and at 212° Fahr. by 1 lb. of petroleum refuse is supposed to take place at atmospheric pressure or in an open boiler, and then only on the condition that before entering the boiler the feed-water has already been heated up to 212° by some other heat than that of the fuel used to evaporate it. On the other hand the 17·1 lbs. theoretically evaporated at $8\frac{1}{2}$ atmospheres effective pressure, or $9\frac{1}{2}$ atmospheres absolute, has been arrived at by the author on the supposition that the feed enters the boiler at what was about its average temperature in the run above mentioned, or from 59° to 60° Fahr. The total heating power of petroleum refuse, according to Messrs. Favre and Silbermann, is 19,832 thermal units, as given in Table XVII; while the heat required to evaporate water from 59° under $8\frac{1}{2}$ atmospheres effective pressure is 1,162 thermal units. Hence $19,832 \div 1,162 = 17 \cdot 1$ lbs. of water is the theoretical evaporation under these conditions by 1 lb. of petroleum refuse. In relation therefore to this figure the above evaporation of 14 lbs., obtained in actual practice with the same cold feed-water, amounts to 82 per cent. In connection with this part of the subject the author has worked out in the accompanying Table XVIII the theoretical evaporative value of petroleum refuse at various boiler pressures and from various temperatures of feed-water.

Although the complete process of burning liquid fuel has not been adopted by Mr. Holden for the locomotives on the Great Eastern Railway, the author is glad to notice that he is nevertheless carrying out a compromise (page 71), such as may prove to be profitable to many English railways having a waste hydro-carbon product for which there is little or no market. From burning the liquid fuel along with coal some economy must ensue, while the

TABLE XVIII.

Theoretical Evaporation in lbs. of Water per lb. of Petroleum Refuse at various boiler pressures and from various temperatures of feed-water.

Temperature of Feed-water.	Absolute Pressure of Steam, in atmospheres.									
	1 atm.	2 atm.	3 atm.	4 atm.	5 atm.	6 atm.	7 atm.	8 atm.	9 atm.	10 atm.
Fahr.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
212°	20·52	20·29	20·13	20·01	19·92	19·83	19·77	19·72	19·70	19·69
176°	19·78	19·57	19·42	19·31	19·23	19·16	19·10	19·05	19·03	19·02
140°	19·10	18·90	18·76	18·65	18·57	18·50	18·45	18·40	18·38	18·37
104°	18·45	18·27	18·14	18·05	17·97	17·90	17·85	17·81	17·78	17·77
68°	17·85	17·68	17·56	17·47	17·40	17·33	17·29	17·25	17·23	17·22
59°	17·70	17·54	17·43	17·33	17·26	17·19	17·15	17·11	17·09	17·08

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engine is still left ready to burn coal alone at any time. In 1874 the author made a similar trial on the Grazi and Tsaritsin Railway, but without a brick arch, burning petroleum refuse along with anthracite. With the oil the fire-box was full of flame; but without it the fire of burning anthracite resembled a coke fire, giving a high concentrated heat. The experiments however were not of sufficient duration for any definite conclusions to be drawn from them: besides which the cost of petroleum refuse at that time was about five times greater than it is now. In place of the two spray injectors adopted by Mr. Holden (page 71), it appears to the author that one alone would suffice, and that there must be a considerable expenditure of steam in using two injectors, each with an extra quantity of steam issuing through the hollow ring R in Plate 22 for inducing a larger air supply. In the employment of the liquid fuel for a scrap-welding furnace at Stratford (page 73), it is mentioned that steam is used for blowing the spray into the furnace; and in the author's experiments he was not able to get a welding heat when using steam for the purpose. It will be very interesting to know the results obtained in the application of the plan to a regenerative furnace, to which Mr. Holden mentions (page 73) that he is now arranging to apply it.

In reference to Mr. Worsdell's remark (page 74) about the Verderber fire-box, it may be mentioned that the plan as originally introduced was intended by Mr. Verderber to do away with the narrow water-spaces surrounding the fire-box, because these on the Hungarian railways soon got choked up with deposit. Moreover such an arrangement completely dispenses with the copper fire-box, which is costly not only as metal but also from the labour involved in making it. The only conclusions in favour of the Verderber furnace which the author can deduce from over three years' experience of the two locomotives fitted with these fire-boxes by way of experiment, as described in the paper, are that the first cost of a copper fire-box is almost completely obviated; while the cost of maintenance is less, and the loss of time from the engine standing in the shops for repair is less than half what it would be in the case of an ordinary fire-box. As to economy of fuel, although the first

comparative trials, as mentioned in page 46, showed results in favour of the Verderber furnace, yet the subsequent experience of a whole year's comparative trial shows only a very small economy in its favour; and practically it may be stated that the consumption of fuel in these two engines with the modified Verderber furnace is the same as in the locomotives with ordinary fire-boxes.

The flashing point of petroleum refuse (page 74) is about 212° Fahr.; and on steamships the Russian government prescribes that no liquid fuel shall be used having a flashing point lower than 126° Fahr. As to the seeming danger of such a large quantity of liquid fuel being in close proximity to the furnace of the locomotive, no accident from this cause has yet taken place on the Grazi and Tsaritsin Railway. In this connection reference may be made to the accident mentioned in the author's former paper, Proceedings 1884 page 289, where a locomotive fired with petroleum ran down the side of a ravine, taking a carriage after it, and not even under these trying circumstances did any conflagration take place. Strict rules embodying proper precautions are drawn up, and no casualties can take place so long as these are adhered to. For instance, no naked light is allowed to be taken into an empty or partially empty petroleum tank; and for such purposes Davy safety lamps are invariably used.

The price of coal (page 74) remains the same as stated in the author's former paper, namely about 27*s*. per ton.

Many if not all of the steamers running from the Black Sea (page 75), and carrying petroleum in bulk, the author believes are already fitted with appliances for burning liquid fuel.

The use of petroleum in any part of the world is no longer an experimental problem, but simply a question of relative cost, as pointed out by Mr. Carbutt (page 75). The best examples of its use in steamboats are the steamers on the Caspian Sea and on the Volga, which in practice have their fires burning from ten to fifteen days at a time without stopping: that is, in the voyage from Astrakhan up to Nishni Novgorod, and also from Astrakhan round the coast of Caucasia and the north coast of Persia, making stops of course in the latter case at ports of call. The author sees no

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practical obstacles to its use in steamers on long voyages, so far as the working of the plan is concerned. But of course the question of insurance crops up, as well as of passengers' safety; and for these two reasons alone it can hardly be expected that for ocean-going steamers, carrying specie, mails, and passengers, the owners will be willing to adopt the plan until further experience has been obtained as to its safety on board ship.

In regard to Mr. Adamson's remark (page 76) that this question of liquid fuel ought to be thoroughly investigated, no doubt it is seemingly in its infancy as yet, and all facts that can be collected of an authentic character ought to be recorded. There are several British possessions which may profit by the use of native petroleum wealth; and it is impossible to predict where petroleum will yet be found in copious quantities.

For the kind manner in which his labours in this exceptional line of engineering have been referred to in the discussion the author is grateful; and any new information or experience which he may obtain in connection with this important subject he will be happy, if of sufficient merit, to communicate to the Institution.

ON COMPOUND LOCOMOTIVES.

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The Compound Locomotive having already been discussed at previous meetings of this Institution (Proceedings 1879 page 328, 1883 page 438, and 1886 pages 297 and 355), the object of the present paper is to furnish an account of some recent practice in designing and working Two-Cylinder Compound Locomotives.

Advantages of Compounding.—It is known that economy in working locomotives has resulted from expanding the steam in more than one cylinder; and this appears to be the only mode of carrying expansion to its full extent in a locomotive. The difference of temperature between the boiler steam and the exhaust is thereby distributed over two cylinders, with the important practical result that there is not so much difference as in the ordinary locomotive between the temperature at the beginning and that at the end of the stroke in each cylinder; consequently there is less initial condensation and less re-evaporation of condensed steam, and a more uniform pressure on the pistons throughout the stroke. For instance, in an ordinary locomotive working with a pressure in the cylinders of say 163 lbs. per square inch above the atmosphere the temperature in the cylinders is continually varying between about 372° Fahr., the temperature of the entering steam, and about 220°, that of the exhausting steam; the walls and covers maintain a mean temperature, and therefore a portion of the fresh hot steam which enters the cylinder is first condensed on the cooler walls and covers, and afterwards when it has cooled down to the low temperature of the exhaust steam, say 220°, it is re-evaporated by the hotter walls and covers. By this process part of the heat of the steam is carried

through the cylinders without being utilised, and the condensed steam, re-evaporated and expanded, goes out of the chimney, and its power is lost. The consequent loss of heat is nearly proportionate to the difference in temperature, namely 152° in this case in each cylinder. In a compound locomotive working at the same pressure of 163 lbs. in the small cylinder, with the temperature of 372°, the pressure in the receiver of the exhaust from the small cylinder will be about 55 lbs., and the temperature about 303°; therefore the range of temperature in the small cylinder is from 372° down to 303°, or 69°, and in the large cylinder from 303° down to about 220°, or 83°. There will thus be a proportionately smaller loss of heat in each of the two cylinders of the compound locomotive, and consequently more work will be obtained from the steam; any condensed steam that may be re-evaporated in the small cylinder is utilised in the large cylinder, instead of going directly up the chimney. Furthermore in the compound engine the clearance space between valve and piston has to be filled with boiler steam in one cylinder only and not in the two; and by the longer travel of the slide-valve in the compound engine the steam is not so much throttled and wire-drawn. Owing to the more constant and even pressure with the compound, the blows on the crank are not so sharp.

The fact that comparatively little attention has until recently been paid to the compounding of locomotives appears to be owing to there having hitherto been considerable complication of parts, in connection both with obtaining a simple device for starting the locomotive, and also with the development of equal power in the high and low-pressure cylinders. These objections have now been overcome in what is known as the Worsdell and v. Borries system, in which the two-cylinder compound locomotive has been brought to a high pitch of efficiency; and from the economical results shown in the present paper the plan is undoubtedly worthy of careful consideration.

Description of Compound Locomotive.—The locomotive illustrated in Figs. 1 to 4, Plates 23 to 25, is a six-wheel-coupled goods engine, which was sent out in 1886 to the Central of Entre-

Rios Government Railway in the Argentine Republic, having been built by Messrs. Dübs and Co., Glasgow. It is one of six goods engines designed by the author; and it was decided to compound this one engine, after investigating the excellent results obtained by the Worsdell and v. Borries plan. As shown in Plate 23, the engine has eight wheels, of which six of 3 ft. 9 ins. diameter are coupled and two are on a leading pony truck; the only difference between this and the five other goods engines is that it has a low-pressure cylinder and a combined intercepting and starting valve, while the axles, connecting and coupling rods, and eccentrics, &c., are all duplicates of those in the ordinary engines.

Intercepting and Starting Valve.—The steam is taken through the regulator in the usual way, and conducted to the high-pressure cylinder by a single steam-pipe A, Figs. 3 and 4. The pipe C, conveying the exhaust steam from the high-pressure cylinder to complete its work in the low-pressure cylinder, is carried round the smoke-box so as to form an intermediate receiver or reservoir for equalising the supply of steam to the low-pressure cylinder. In its course is placed at X the combined intercepting and starting valve, the construction of which is shown in Figs. 11 to 14, Plate 26. In regular running with steam on, the large intercepting valve V stands full open, as shown in Fig. 11, allowing a free passage for the exhaust steam from the high-pressure cylinder to the valve-chest of the low-pressure; while at the same time the small starting valve S on the spindle of the intercepting valve is closed. But before the regulator is opened for starting the engine, the intercepting valve V is closed by the driver, Fig. 13, by means of a lever pressing on the projecting end of the spindle, whereby also the starting valve S is opened at the same time. On then opening the regulator, the boiler steam passing through the small pipe B and along narrow channels cut in the valve spindle makes its way past the starting valve S direct to the low-pressure cylinder, while at the same time it is prevented by the closed intercepting valve V from passing backwards into the exhaust end of the high-pressure cylinder. By its passage

through the small pipe B and the narrow channels in the valve spindle, the boiler steam is so wire-drawn that its pressure on reaching the low-pressure cylinder is about half of that on the high-pressure side, thus giving equal force to both pistons, the area of the larger cylinder being about double that of the smaller. The boiler steam consequently acts simultaneously upon both pistons at the moment of starting, causing both cylinders to start with their full tractive power, as in an ordinary locomotive, and without back pressure on the small piston.

Immediately however that the engine has started, and the high-pressure piston has made its first single stroke, the exhaust steam from the high-pressure cylinder, passing over through the intermediate pipe C, comes in contact with the closed intercepting valve V; and acting upon its large area opens it automatically against the pressure of the wire-drawn boiler-steam on the other side and against the atmospheric pressure acting on the valve spindle. The same movement closes the small starting valve S, thereby cutting off all further access of boiler steam to the low-pressure cylinder. The engine then commences at once to work as a compound.

By this simple arrangement it will be seen that no steam can be wasted by the driver, inasmuch as no exhaust ever takes place from the high-pressure cylinder into the atmosphere; and the driver cannot interfere with the arrangement, however much he might be tempted to work the low-pressure cylinder with direct boiler steam, instead of with steam properly expanded from the high-pressure cylinder.

In order still further to facilitate the convenience of the driver by sparing him the necessity of closing the intercepting valve before opening the regulator, and also in order to do away with packing rings or glands, the modified arrangement shown in Figs. 15 to 21, Plate 27, has been devised for closing this valve automatically by means of the direct boiler steam admitted on opening the regulator, so that the closing of the intercepting valve cannot now be omitted through any negligence on the driver's part; it is done for him, and he is thus obliged to use both the cylinders when starting, thereby

obviating any strain on the high-pressure side of the engine, which might be caused by trying to start with the high-pressure cylinder alone, and which would produce a jerk on the train. This modification consists in attaching to the back of the intercepting valve V two small rams RR, Fig. 16, which together constitute the starting valve, and cover two small ports in the casing surrounding the valve spindle. As soon as the regulator is opened for starting the engine, the boiler steam passing along the small branch pipe B presses upon the ends of these rams, and thereby closes the intercepting valve automatically, Fig. 18; while in the same movement the rams uncover the two small steam ports, through which the boiler steam makes its way direct to the steam-chest of the low-pressure cylinder. On starting, the exhaust from the high-pressure cylinder fills the receiver with steam, and as soon as the pressure is sufficient opens the intercepting valve, Fig. 16, against the boiler pressure acting on the ends of the small rams only and against the atmospheric pressure on the end of the valve spindle and against the wire-drawn steam on the low-pressure side of the valve. The intercepting valve is kept open by the pressure in the receiver, against the atmospheric pressure on the end of the valve spindle, which in this case is more than double the pressure of the boiler steam on the two rams. The back valve-face prevents steam from passing out from the receiver along the valve spindle; and should any slight leakage take place on starting, before this valve is seated, the steam so escaping is carried into the smoke-box by the pipe P. The opening of the intercepting valve V causes the two rams RR at the same time to cover the two small ports, Fig. 16, thereby cutting off the boiler steam from the low-pressure cylinder. At D is a relief valve loaded to 90 lbs. per square inch. In practice it takes only from half to one revolution before the exhaust from the high-pressure cylinder opens the intercepting valve and closes the starting valves. This modification, rendering both the closing and the opening of the valve alike wholly automatic, has already been fitted to about 150 engines, including those now being built by Messrs. Beyer Peacock and Co., Messrs. Neilson and Co., and Messrs. Sharp Stewart and Co. It will thus be seen that the driver when starting

the engine has no more handles to move than on the ordinary engine; he merely places the reversing lever in either front or back gear as required, and opens the regulator in the usual way. Thus all complication or risk of mistake is avoided.

Cylinders.—These are placed outside the frames, according to the custom on the Argentine railways, in order to keep down the centre of gravity, in view chiefly of the liability otherwise involved of the engine turning over when throwing cattle off the line, should they get underneath the engine. The outside cylinders also enable the crank axle to be dispensed with, which is an advantage in a country far away from the maker. The high-pressure cylinder is 16 inches diameter, and the low-pressure 23 inches, which gives a ratio of 1 to 2·1; the stroke is 24 inches. These proportions have proved in practice to be very efficient.

Slide-Valves and Valve-motion.—The valve gear, shown in Figs. 22 to 25, Plate 28, consists of the usual Stephenson link-motion, with a simple device for effecting a very advantageous distribution of steam for the compound locomotive. By a slight difference in the length of the lifting links or in the position or angle of the levers on the reversing shaft, the cut-off in the high-pressure cylinder is kept at an earlier point of the stroke than in the low-pressure cylinder, when running in forward gear: which gives an ascertained economy in working, and also equalises the amount of work done in the two cylinders. In other respects the valve gear is not in any way different from that on other goods engines for this railway. When working in back gear with this arrangement, the differential relative expansion obtained in the forward gear is reversed, the cut-off taking place earlier in the low-pressure than in the high-pressure cylinder; and therefore the sector of the reversing lever is fitted with only a single notch for full gear when running backward. This is of little consequence for engines running chiefly forward; and it is better to take advantage of this simple contrivance for forward gear, without complicating it by any supplementary arrangement for obtaining equal cut-off in both cylinders in the back gear. On

engines running as much in one direction as the other the differential cut-off is applied to both forward and back gear, and is controlled also by one reversing lever; the arrangement may be applied to any class of valve gear, and its effect is illustrated in Table 15 appended, which shows the steam distribution in a tank engine running as much in one direction as in the other. For the ordinary link-motion the differential cut-off is effected by setting the eccentrics of the low-pressure cylinder at suitably smaller angles of advance than those of the high-pressure; and for Joy's gear, by making the lever attached to the low-pressure valve-spindle slightly shorter than that to the high-pressure. Also the lap of the low-pressure valve must be reduced accordingly, in order to obtain the proper lead.

In Table 14 appended are shown the different relative degrees of expansion in the high and low-pressure cylinders of the goods engine on the Entre-Rios Railway, both valve-gears being controlled by the same single reversing lever. For backward gear the full-gear notch is the only one cut in the sector.

The principal dimensions of the two valve-gears are as follows:—

			High-pressure.	Low-pressure.
Cylinder, diameter and stroke			16 ins. × 24 ins.	23 ins. × 24 ins.
Length of connecting-rod			6 feet	6 feet
Throw of eccentrics			$6\frac{1}{4}$ inches	$6\frac{1}{4}$ inches
Angle of advance, forward gear			4°	4°
" " " back			14°	14°
Travel of valve, full gear forward			$3\frac{1}{2}$ inches	$3\frac{3}{4}$ inches
" " " " " back			$3\frac{13}{16}$ inches	$3\frac{5}{8}$ inches
Opening of ports in full gear	Front port	forward	$\frac{3}{4}$ inch	$1\frac{1}{8}$ inch
		back	$\frac{3}{4}$ inch	1 inch
	Back port	forward	$\frac{13}{16}$ inch	$1\frac{1}{8}$ inch
		back	$1\frac{1}{8}$ inch	$1\frac{1}{8}$ inch
Slip of die, full gear forward			$\frac{3}{4}$ inch	$\frac{3}{4}$ inch
" " " " " back			$\frac{1}{2}$ inch	$\frac{3}{8}$ inch
Clearance of die, full gear forward			$\frac{3}{4}$ inch	$\frac{3}{8}$ inch
" " " " " back			$\frac{3}{8}$ inch	$\frac{3}{4}$ inch
Lap of valve			1 inch	1 inch
Steam-ports, size of each			$1\frac{1}{4}$ in. × 14 ins.	$1\frac{5}{8}$ in. × 17 ins.
" " area of each			$17\frac{1}{2}$ sq. ins.	$27\frac{5}{8}$ sq. ins.
Cut-off in forward gear, ordinary running			40 per cent.	50 per cent.

The steam-ports and slide-valves are shown in Figs. 23 and 25, Plate 28, and Figs. 5 and 6, Plate 25. The low-pressure steam-ports are large, having each an area of 27·625 square inches against a piston area of 415·476 square inches, or a ratio of 6·65 per cent. The high-pressure steam-ports have each an area of 17·50 square inches against a piston area of 201·06 square inches, or a ratio of 8·7 per cent.

Pistons.—The low-pressure piston of 23 inches diameter is constructed of wrought cast-steel in order to make it as light as possible for so large a piston. The high-pressure piston of 16 inches diameter is made of cast-iron and of the usual form. The piston-rods are arranged to work through the front cylinder-covers, which is desirable when there is room, in order to support the weight of the pistons. For the low-pressure cylinder this is especially advisable; and in the present instance the high-pressure cylinder is also treated in the same way, so as to be uniform. The front rods work through glands and hollow sleeves, closed at their extremities to protect them from dust, with the exception of small holes for the air to escape.

Boiler.—The boiler is made of best Yorkshire iron, and is double-riveted; the longitudinal seams are butt-jointed with cover plates both inside and outside. The barrel is telescopic in shape, the smallest diameter being at the smoke-box end, thus giving the necessary drainage backwards to the blow-off cock. The front shell-plate is secured to the smoke-box tube-plate by a faced angle-iron ring, bored out for the reception of the shell-plate and riveted zigzag to it. All the rivet holes are accurately drilled, and the riveting is done by hydraulic pressure. The boiler is made up of seven plates:—three for the barrel, one for the sides and top of the fire-box shell, one throat plate, one back plate, and the front tube-plate. The dome consists of two plates, both of which are flanged and welded together solid; and the shell is strengthened internally, where cut out for the manhole and dome. All the plates for the boiler were carefully tested, both with and

across the grain, in addition to the usual bending tests; the specified test for plates is a tensile strength of 22 tons per square inch in the direction of the grain, with a contraction of area of 22 per cent. at the point of fracture; and across the grain a tensile strength of 20 tons, with a contraction of 15 per cent.; this makes a splendid material for boilers, and the plates prove practically to possess the same strength both with and across the grain. The side plates of the fire-box shell are lapped round the lower corner of the back and front plates, so as to form a double thickness for the tapping of threads for the mud plugs. The boiler is clothed with sheet-iron, secured to a skeleton of angle-iron, and made as air-tight as possible, no wood lagging being used. This air jacket is found much preferable to other methods; for, when wood lagging or other material is used, it quickly decays, in the course of about a year or two, and ceases to be of much good.

Inside Fire-box.—The inside fire-box is made of copper. Each sheet was tested, and showed an average tensile strength of about 14·34 tons per square inch, with a contraction of area of about 46 per cent. at the point of fracture. The fire-box tube-plate is 1 inch thick, where drilled for the reception of the tubes, and is reduced to $\frac{5}{8}$ inch thickness below the tubes; the back and top and side plates are $\frac{1}{2}$ inch thick, and are secured to the shell plates by $\frac{7}{8}$-inch copper stays, which have a tensile strength of about 17 tons per square inch with a contraction of area of 43 per cent. The stays are spaced 4 inches apart, and are tightly screwed into the inside and outside fire-box plates with twelve threads to the inch. The roof of the fire-box is stayed with corrugated wrought-iron bridge-stays and suspension links. This is considered by the author to be the best means of staying fire-box tops, as it gives the fire-box a longer life, owing to the freer expansion thus allowed. In some engines built on the Continent, for railways with which the author is connected, direct stays have been used; but there is no doubt that, though these secure a much better distribution of water over the fire-box top and allow of its being more easily kept clean, yet unless very carefully arranged they are apt to crack the

fire-box tube-plate, owing to the upward expansion of the copper box.

Tubes.—There are 171 brass tubes, having an outside diameter of 2 inches; their thickness at the smoke-box end is 13 B.W.G. or 0·095 inch, and at the fire-box end 11 B.W.G. or 0·125 inch. They are slightly enlarged at the smoke-box end, in order to allow of their being withdrawn. At the fire-box end they are rolled and beaded over, and a turned steel ferrule is driven in tightly, which assists in securing the tube and also protects its end from the fiercest action of the flame. At the smoke-box end the tubes are merely rolled in their places, not beaded, and the ends are left projecting $\frac{3}{16}$ inch from the tube-plate.

The heating surface is 912 square feet in the tubes, and 104 in the fire-box, total 1,016 square feet; the grate area is 18 square feet. It will thus be seen that the boiler is of the usual modern make; and it is built to stand a working pressure of 175 lbs. per square inch above atmosphere. It is somewhat larger than is customary for cylinders of the same size in this country, on account of the fire-box being here increased in size for the purpose of burning either wood or coal; and the author has found that plenty of steam room is of great advantage, where bad water and fuel have to be contended with. The smoke-box is large, to allow for a suitable spark-arrester and deposit for ashes. The cattle-thrower or cow-catcher is made of wood, extending well out in order to be easy on the cattle; the buffers are hinged on the footplate out of their way. All sponge-boxes, both for engine and tender, are arranged so as to be easily taken down and the bearings examined without lifting. The motion is cased in as much as possible, to protect it from the dust.

Steam Pressure.—The working pressure in the engine illustrated in Plate 23 is 175 lbs. per square inch above atmosphere. In compound locomotives it is found advisable to increase the pressure as much as possible, because the expansion of high-pressure steam can be more effectually carried out in two cylinders, and with consequently greater economy. It is not essential however to the

compound system to work at a higher pressure than in an ordinary engine; but the economy resulting is somewhat less if a higher pressure be not used. Thus by compounding existing engines without increasing their pressure an economy of only from 10 to 15 per cent. may be obtained. In Table 3 it is seen that there are ordinary engines working at the same pressure as the compounds; and Mr. v. Borries finds but little economy is obtained in ordinary engines by using the higher pressure.

Steaming.—It is found that the steaming qualities of the compound locomotive are very favourable, owing most probably to the easy and more even stream of exhaust, uninterrupted by violent blasts or puffs as in the ordinary engine, which have the effect of pulling the fire about. Much fewer sparks are thrown out from the chimney, and as a consequence in many cases the spark-arrester can be done away with.

Variable Blast-Nozzle.—The engine illustrated is arranged to use either the ordinary blast-nozzle, or a variable one which is sometimes used on the Argentine Government Railways when the fuel burnt is wood, and when it is not of a reliable quality. The variable nozzle has no essential connection with the compound locomotive, and may be applied only when required, and when the driver will use it judiciously. The ordinary nozzle is shown in Fig. 3, Plate 24; it is $4\frac{1}{2}$ inches diameter or $15 \cdot 9$ square inches area, and is cylindrical for a length of $3\frac{1}{2}$ inches; it is about $\frac{1}{2}$ inch larger in diameter than that usually employed for the ordinary engine.

Starting Arrangement.—An intercepting valve of any shape may be used for the purpose of shutting off the low-pressure steam-chest from the high-pressure exhaust at the moment of starting. A flap or a disc valve is generally employed; the engine here referred to is fitted with a disc valve, as illustrated with a slight modification in Plate 27. This construction has the advantage that, in addition to the intercepting valve being closed by direct steam from the regulator, there is only the receiver pressure on its spindle for a

short time while it is closed; and when it is open its boss seats itself against the inside of the cover, and so prevents steam from leaking along the spindle out into the atmosphere; thus the need of packing rings on the valve spindle is done away with. The object of this combination of valves is to enable the engine to start always with boiler steam in both cylinders as in an ordinary locomotive; it also prevents any unequal strain on the machinery or the couplings of vehicles, and enables a heavy train to be moved easily and smoothly without any shock and with full power on both pistons, and without any steam being wasted. This arrangement is found to be most advantageous, as it will be seen that a compound locomotive may be handled in the same manner as an ordinary engine, when starting, shunting, ballasting, or working trains. In fact these compounds start more quickly than the ordinary engine; and this is especially advantageous in cases of emergency, and with tram engines which start on any gradient quite easily. Immediately that the load is moved, the engine by this arrangement is automatically converted into a compound, in which condition it continues working until a stoppage is made or the steam is shut off. The receiver or reservoir should be large enough to contain about one high-pressure cylinderful of steam during the short period of the first revolution, when starting: that is, its capacity should be at least equal to that of the high-pressure cylinder. The diameter of each of the two starting valves R, Fig. 16, Plate 27, is $\frac{5}{8}$ inch, and their combined area 0·613 square inch, while the diameter of the spindle of the intercepting valve V is 2 inches and its area 3·142 square inches, which leaves ample surplus for keeping the intercepting valve open against the direct boiler pressure on the rams RR; or if desired, the spindle and the surface behind the intercepting valve, where it bears against the casing at J, may be made larger, for enabling the exhaust pressure on the face of the intercepting valve more easily to overcome the boiler pressure on the starting valves RR. When the low-pressure cylinder is large, it is advisable to place a relief valve on the low-pressure side of the intercepting valve, in order to avoid any over-pressure and consequent straining of the mechanism; but in practice

up to cylinders of 24 inches diameter this has not been found necessary. The low-pressure cylinder mud-cocks are also sometimes fitted with a spring, as a safe-guard against over-pressure.

Trial Trips.—As the compound goods engine illustrated in Plate 23 has the ordinary English gauge of 4 ft. $8\frac{1}{2}$ ins., Messrs. Dübs kindly arranged for the engine to make a trial trip on the Caledonian Railway. Accordingly on Friday, 20th August 1886, the engine was taken out of the shops to the Polmadie running sheds, whence at 10.30 A.M. it started on a trip of 14 miles to Coatbridge, attached to a train of 23 wagons all loaded with iron ore, and a brake van, the gross load being about 300 tons, inclusive of 50 tons for a pilot engine and tender, running dead, which the railway authorities considered it advisable to attach on this first trip. The average steam pressure in the high-pressure steam-chest was 163 lbs. per square inch, and in the low-pressure steam-chest 55 lbs. The speed was 17 miles an hour. The return journey was made from Coatbridge at noon, with pilot engine and van only.

On the afternoon of the same day, another trip was made at 2.30 from the Polmadie sheds, on the Carstairs route, when the engine was attached to 45 empty wagons and a brake van, the gross load being about 209 tons. The average steam pressure in the high-pressure steam-chest was 163 lbs. per square inch, and in the low-pressure 55 lbs.; the highest steam-chest pressures were 170 lbs. and 70 lbs. respectively. The average speed was about 17 miles an hour. The efficiency of the starting and intercepting valves was thoroughly well proved; the 45 wagons and brake van, forming a train of about 700 feet in length, were moved out of the siding on a stiff gradient and reverse curve, without the resistance overcoming the adhesion. The return journey was made with brake van only.

Another and final trip was made on the following Monday, 23rd August 1886, the run being to Greenock and back on the Caledonian line, a total distance of 45 miles. The engine left the Polmadie sheds at 10.30 A.M., with 39 loaded coal wagons and a brake van, the gross load being about 418 tons; and returned from Greenock at 2.45 P.M. tender foremost, with 36 loaded limestone wagons and the

brake van; the gross load being about 403 tons. The boiler pressure was maintained with ease throughout the journey, and the speed was about 30 miles per hour. A blast area of 20 square inches was found to be the most economical opening of the blast nozzle. The wind was calm and the rails were dry, on both down and up journeys. Owing to the various stoppages for traffic and other delays at stations, no accurate return of the coal consumption can be given on this trial, which was practically made to see that the engine was all right and started properly. The steepest gradient is 1 in 102 at Shields Bridge. As this trial was considered most satisfactory for practical purposes, it was not deemed necessary to carry out any further experiments for scientific results. The engine started quite easily with a very heavy load; in fact it starts with a heavier load than an ordinary engine of the same size, which is accounted for by the action of the automatic intercepting valve.

As to the commercial result of the working of this goods engine since it was sent out, no information has yet reached the author, and since its arrival it has probably been used in the construction of the line, which is a new one; all that is known is that it is working very satisfactorily.

Commercial advantage of Compounding.—There are now (November 1888) about 360 engines, including tram engines, on the Worsdell and v. Borries system, either at work or in construction or ordered; the statement in Table 1 appended shows where they are, and gives a description of the class of engine. In 1886 there were only between 50 and 60 engines at work; there has thus been an increase of six times in a couple of years.

The economy in fuel over the ordinary engines ranges from $14\frac{1}{2}$ to 20 per cent., and in some cases still more, as seen from Tables 2, 8, 9, and 12.

In the locality where the goods engine illustrated is working, coal costs at least £2 per ton; presuming an ordinary engine runs 30,000 miles in a year at 25 lbs. per mile, which is about the consumption for such an engine, it will have burnt 335 tons, which at £2 per ton cost £670; the compound effecting a saving of 20 per

cent. will accordingly save £134 in a year. It is found that a compound locomotive of less weight can haul as heavy a train at the same speed as an ordinary locomotive, provided the adhesion is sufficient, with the economy of from 14½ to 20 per cent.; and as the cost of the compound is no greater for such an engine, the 20 per cent. or £134 saved in a year is a net saving per engine, not taking into account the cost of haulage on the 20 per cent. reduction of fuel and water. As there is so much less fuel and water used in the boiler, it is natural that there must be less wear and tear of fire-box and tubes, and less deposit, &c.; it is consequently to be presumed that the boiler of the compound will last longer than that of the ordinary engine. Then again it is found there is no more actual wear on the compound engine, as previously explained; and both the high and low-pressure cylinders develop approximately the same horse-power, consequently there can be no more wear on one side than the other. Compound express engines working the heaviest service, which run about 3,000 miles per month, are found by Mr. v. Borries to do some 15 per cent. more mileage between shop repairs than the ordinary engines of the same size and class; and the intercepting valve shown in Plate 26 works for about two years with only the renewal of the spring rings on the valve-spindle.

It is customary, when not otherwise specified, to make the size of the high-pressure cylinder of the compound the same as that of the cylinder of an ordinary locomotive, but to use a higher boiler pressure in the compound. Such engines are found to haul from 5 to 10 per cent. heavier trains while saving about 10 per cent. of fuel. The tender may be left the same size, thus allowing the engine to run further with the same water and fuel. There is therefore an extra weight due to the increased size of the low-pressure cylinder, piston and receiver, and the combined intercepting and starting valve: less one steam pipe in the case of outside cylinders, and the difference between a single and a double exhaust. Compound engines for new railways, where it would not be necessary to take into account existing engines and tenders, could be built at less weight and less cost for the same power, owing to their greater

efficiency. Comparing, for instance, the compound goods locomotive illustrated in Plate 23 with the ordinary engines weighing full about $36\frac{1}{2}$ tons: as there is a saving of from $14\frac{1}{2}$ to 20 per cent. of fuel, the grate area and heating surface may be reduced in proportion, and also the boiler slightly; and the boiler not being so large will bear a somewhat higher pressure, while the weight of water in it will also be less. These items make a considerable difference, for the boiler alone weighs about $8\frac{3}{4}$ tons, and the water it contains about 2 tons 8 cwts., making a total weight of 11 tons 3 cwts.; of which about $1\frac{1}{2}$ tons may be saved with the compound. Again the motion-work, springs &c., may be made somewhat lighter, as the strain on the compound is not so great as on the ordinary engine. Without taking this into consideration however, there is a saving in metal of about $\frac{3}{4}$ ton in the boiler alone. The tender of the engine illustrated in Plate 23 weighs about 13 tons 3 cwts., and the water about 7 tons 6 cwts. when full, making $20\frac{1}{2}$ tons; 20 per cent. off is about 4 tons 2 cwts. Here again there is a saving of say 2 tons of metal in favour of the compound. Thus the saving of metal in the engine and tender amounts to about 3 tons. The cost of the compound for the same power is thus brought to about the same as that of the ordinary engine, or rather less. The engine and tender being lighter and requiring less coal and water, there is a consequent saving in the hauling.

In Plates 29 and 30 is illustrated a compound bogie passenger engine now working the Scotch express on the North Eastern Railway between York and Edinburgh, being one of Mr. Worsdell's compounds specially designed for this service. The cylinders are 18 and 26 inches diameter with 24 inches stroke, and the driving wheels 6 feet $8\frac{1}{4}$ inches diameter. This engine is fitted with Joy's valve-gear.

In Plate 32 is shown the smoke-box end of a compound passenger engine now being built by Messrs. Neilson and Co. for the Santa Fé and Cordoba Great Southern Railway, having outside cylinders with the steam-chest above, for which the steam distribution is given in Table 16.

In Table 1 are given the number, class, and principal dimensions of some of the compound engines on this system on various railways. Tables 2 to 12 show the actual saving on some of these lines.

In Tables 8 and 9 are shown the results of the comparative trials on the Buenos Aires and Rosario Railway with the compound passenger engine, No. 34, built by Messrs. Beyer Peacock and Co. from the designs of Messrs. James Livesey and Son. This engine is one out of six ordinary passenger engines that were being built, of exactly the same class, and was compounded for the purpose of giving the system a trial. The weight of train and conditions of running were the same in both cases. The result has been that six more compounds of the same class have been ordered.

In August 1888 a special report was received that this compound engine, No. 34, had then been in constant service for a period of fifteen months, and had run about 62,000 miles, and the results had been very satisfactory. During that time the engine had been chiefly employed with the mixed and passenger trains between Buenos Aires and Baradero, the speeds being respectively 25 and 30 miles per hour, exclusive of stoppages, while the loads hauled were in the mixed trains 50 axles as a maximum and in the passenger trains 26 axles as an average. During the four months of February to May 1888 the total mileage was 16,935 miles, the average consumption of coal 23·09 lbs. per mile, and of oil 8·76 lbs. per 100 miles, the boiler pressure being 160 lbs. per square inch. The compound was found to run as steadily at all speeds as the non-compounds; the starting valve worked exceedingly well, and allowed the engine to get away with its load quite as easily as the non-compounds; and the compound worked its trains with punctuality. After a performance of 62,000 miles it appeared to be in remarkably good order. The brass slide-valves of both cylinders, as well as the cylinder valve-faces, were found with a good true and smooth surface; they had not required any repair or re-surfacing, while their wear was small for the mileage run, namely:—the flange of the high-pressure valve, 7-8ths inch thick when new, had worn down to 11-16ths inch full at bottom and $\frac{3}{4}$ inch at top; and that of the low-pressure valve, originally 1 inch thick, had worn

down to 7-8ths inch thick. This was altogether a superior result to that obtained with any of the five non-compounds, and was thought to be due in a great degree to the use of the steam lubricator worked from the footplate; but the author considers it is to be attributed to the fact of the pressure under which the slide-valves work being much less than in an ordinary engine with the same boiler pressure. The piston rings had once been replaced. The eccentric sheaves were still in good order, as were also the cast-iron liners. The wear of the connecting-rod large-end brasses and coupling-rod bushes had not been in any way extraordinary. All other parts of the motion had given good results, and the engine wheel tires were still in good order. The boiler maintained steam fully with the blast-pipe nozzle 4·94 inches diameter.

Four compounds are now being built by Messrs. Kitson from the designs of Mr. E. Harry Woods for the North Western Argentine Railway of metre gauge; this is also owing to the satisfactory results of the two already at work on the line, which were tried against the ordinary engines built from the same design and working at the same boiler pressure of 160 lbs. per square inch.

Table 13 gives comparative cost of repairs; and Tables 14 to 16 show steam distribution in different compound locomotives.

Indicator diagrams from various of these compound engines are shown in Plates 33 to 35. Those in Plate 33 are from a passenger engine on the North Eastern Railway, and those in Plate 34 from a goods engine on the same line. Fig. 38, Plate 35, is from a passenger engine, and Fig. 39 from a goods engine, on the Hannover State Railways.

In designing the engine illustrated in Plates 23 to 28 the author introduced in the details sundry modifications to meet the exigencies of the country it was intended for. These modifications he has found, after a number of years' experience as locomotive superintendent in that country, to be of importance; but their enumeration might prove tedious.

The author desires to thank Mr. Worsdell and Mr. v. Borries and other engineers for information and statistics which have been of great use to him in compiling this paper.

TABLES 1 to 16.

TABLE 1. (*continued on opposite page*)

List of Goods and Passenger Compound Locomotives at work, in construction, and ordered. November 1888.

The dimensions given relate to some only of the engines.

Railway.	Class and Number of Engines.		Number of Wheels coupled.	Driving Wheels. Diameter.		Cylinders. Diameters.		Cylinders. Stroke.	Boiler Pressure per sq. in. above atm.	Weight in working order.
	Class.	No.	No.	Feet.	Ins.	Ins.	Ins.	Inches.	Lbs.	Tons.
North Eastern	Goods	72	Six	5	$1\frac{3}{8}$	18	26	24	160	40·35
	Pass.	14	Four	6	$8\frac{3}{4}$	18	26	24	175	42·45
Great Eastern	Goods	1	Six	4	10	18	26	24	150	39·40
	Pass.	11	Four	7	0	18	26	24	160	44·50
London and South Western	Pass.	1	Four	7	1	18	26	24	160	45·80
Bengal and Nagpur	Mixed	4	Six	4	4	18	26	26	161	46·70
Prussian State	Goods	70	Six	4	$4\frac{3}{8}$	$18\frac{1}{8}$	$25\frac{5}{8}$	$24\frac{3}{4}$	176	37·75
	Pass.	59	Four	6	$1\frac{1}{4}$	$17\frac{3}{8}$	$24\frac{3}{4}$	$24\frac{3}{4}$	176	38·35
Alsace and Lorraine	Pass.	1	Four	4	11	$14\frac{1}{2}$	$21\frac{5}{8}$	$19\frac{3}{4}$	176	31·50
Western of Buenos Aires	Pass.	2	Four	5	11	$16\frac{1}{2}$	24	24	175	38·75
Central of Entre Rios	Goods	1	Six	3	9	16	23	24	175	37·00
Buenos Aires and Rosario	Pass.	7	Four	5	$7\frac{1}{2}$	16	$23\frac{1}{4}$	24	160	37·14
North Western Argentine	Mixed	6	Six	4	0	16	23	22	170	32·50
Argentine Central Northern	Goods	27	Eight	3	6	16	23	24	175	33·00
	Pass.	11	Four	4	6	15	$21\frac{1}{2}$	22	175	29·50

TABLE 1. (*continued from opposite page*)

List of Goods and Passenger Compound Locomotives at work, in construction, and ordered. November 1888.

The dimensions given relate to some only of the engines.

Railway.	Class and Number of Engines.		Number of Wheels coupled.	Driving Wheels. Diameter.		Cylinders. Diameters.		Cylinders. Stroke.	Boiler Pressure per sq. in. above atm.	Weight in working order.
	Class.	No.	No.	Feet.	Ins.	Ins.	Ins.	Inches.	Lbs.	Tons.
Saxony	Goods	15	Six	4	$6\frac{3}{4}$	18	$25\frac{1}{2}$	24	176	40·80
	Pass.	10	Four	6	$1\frac{3}{4}$	$17\frac{1}{4}$	$24\frac{3}{4}$	$21\frac{5}{8}$	176	42·30
Wurtemburg	Pass.	5	Four	5	5	$16\frac{1}{2}$	$23\frac{5}{8}$	22	176	36·40
Nizam State	Mixed	2	Six	4	3	18	26	26	161	44·85
Santa Fé and Cordoba Great Southern	Goods	6	Six	4	6	$17\frac{1}{2}$	25	25	170	46·75
	Pass.	4	Four	5	6	16	23	24	170	38·50
Central Argentino	Goods	5	Six	4	6	18	26	24	165	43·70
	Pass.	5	Four	5	$1\frac{1}{2}$	18	26	24	165	44·00
Italian Meridional	Goods	2	Six	4	5	18	$25\frac{5}{8}$	$25\frac{5}{8}$	180	38·00
Argentine Great Western	Mixed	8	Six	4	3	$17\frac{1}{2}$	25	24	175	
Moscow and Warsaw	Goods	1	Six							
Anglo-Chilian Nitrate	Goods	9	Eight	3	2	17	24	21	170	51·00
Manchester Bury Rochdale and Oldham Tramways	Pass.	1	Four	2	7	9	14	14	180	12·80
Rossendale Tramway	Pass.	1	Four	2	6	9	14	14	180	10·00

TABLE 2.—*Economy of Fuel in Compound Locomotives on continental railways.*

For particulars of Locomotives see Table 3.

No. of Trial.	Locomotive. See Table 3.	Locomotive. Number tried.	Section of line on which trials were made.	Steepest Gradient.	Length of Trial.	Date of Trial.	Coal consumed per 100 axle-miles.	Economy of Compound engine.	Remarks.
No.	Class.	No.			Months.		Lbs.	Per cent.	
1	C 1 O 3	One One	Göttingen to Cassel Göttingen to Hannover	1 in 64 1 in 80	2	Summer 1883	49·32 59·96	17	Goods train starting from Göttingen.
2	C 1 O 4	One Two	Göttingen to Cassel	1 in 64	2	Autumn 1883	73·80 92·25	20	Two special trains on mountain sections only.
3	C 1 O 1	Two Ten	Göttingen to Cassel Göttingen to Hannover Hannover to Minden	1 in 64 1 in 80 1 in 200	9	1 July 1883 to 1 Apr. 1884		21	Saving calculated from average actual consumption and ordinary consumption.
4	C 2 O 5	One One	Ottbergen to Northeim	1 in 100	9	1 Oct. 1883 to July 1884		17	Omnibus trains. Saving calculated as in No. 3.
5	C 1 O 1	One Four	Frankfort-on-Main to Bebra	1 in 100	2	Summer 1884	57·98 67·66	14·3	Goods trains, starting from Frankfort.
6	C 1 O 1	One One	Mountain sections		2	Summer 1884	60·67 72·03	16	Special trains.
7	C 1 O 2	One One	Minden to Hannover	1 in 200	2	Autumn 1884	46·48 55·35	16	Special trains.
8	C 3 O 6	One One	Hannover to Hamburg	1 in 300	2	Nov. 1884 to Jan. 1885	127·73 152·56	16	Special trains, one passenger train and one express.
9	C 3 O 7	One Two	Minden to Hannover Minden to Dortmund	1 in 200 1 in 300	2	Nov. 1884 to Jan. 1885	145·47 170·30	14·5	Three passenger trains, one mail and two expresses.
10	C 1 O 1	One One	Deutz to Giesen	1 in 80	4	April to July 1885	64·58 76·64	16	Goods trains, starting from Deutz.

TABLE 3.

Particulars of Locomotives used for trials in Table 2.

Locomotive.		Number of Wheels coupled.	Driving Wheels.	Cylinders.		Boiler Pressure per sq. in. above atmosphere.	Heating Surface.	Grate Area.	Weight in working order.
Class.	Description.		Diameter.	Diameter.	Stroke.				
		No.	Inches.	Inches.	Inches.	Lbs.	Sq. Feet.	Sq. Feet.	Tons.
C 1	Compound Goods .	Six	52·36	18·11 25·59	24·80	176	1308·9	16·47	38·5
O 1	Ordinary Goods .	Six	52·36	17·72	24·80	146	1340·2	16·47	37·9
O 2	Ordinary Goods .	Six	52·36	17·72	24·80	176	1340·2	16·47	38·1
O 3	Ordinary Goods .	Six	54·02	17·01	24·02	132	1259·4	18·30	36·4
O 4	Ordinary Goods .	Six	51·10	19·02	24·02	176	1345·5	21·53	42·3
C 2	Compound Omnibus*	None	44·49	7·87 11·81	15·75	176	247·6	5·81	17·7
O 5	Ordinary Omnibus* .	None	44·49	7·87	15·75	176	247·6	5·81	17·7
C 3	Compound Express .	Four	73·23	16·54 23·62	22·84	176	1054·9	18·84	37·4
O 6	Ordinary Express .	Four	73·23	16·54	22·05	146	1038·7	19·38	34·4
O 7	Ordinary Express .	Four	77·95	16·54	20·08	146	1334·8	16·68	42·8

* The designation "omnibus" is applied to engines taking trains of four or five carriages which stop at every station: such as short parliamentary or local trains in England.

TABLE 4.

Comparative Trials of Compound and Ordinary Locomotives on the Prussian State Railway between Paderborn and Soest and Altenbeken.

1 July to 31 December 1887.		Compound.	Ordinary.
Numbers of Engines	nos.	1173, 1174 1175, 1176	1161, 1162 1164, 1165
Cylinders, diameters	inches	18·11 25·59	17·72
,, stroke	inches	24·8	24·8
Driving Wheels, diameter	inches	52·3	52·3
Heating surface	square feet	1291·7	1345·5
Grate area	square feet	16·68	16·68
Boiler pressure, lbs. per sq. inch above atm. .	lbs.	176	146
Weight in working order	tons	38·3	38·3
Distance run	miles	43,372	41,831
Coal allowed for trials	lbs.	2,705,272	2,725,328
,, actually consumed	lbs.	1,738,674	1,989,227
,, consumption in percentage of allowance	per cent.	62	73
,, consumption per mile	lbs.	40·08	47·55
,, saving in Compound engine . .	per cent.	15	
Water, saving in Compound engine . .	per cent.	20	

Between Paderborn and Soest, distance 43·496 miles, with 15·534 miles of 1 in 250 to 1 in 300. Between Paderborn and Altenbeken, distance 10·563 miles, with 10·563 miles of 1 in 100.

The coal consumption includes lighting up and shunting. The water consumption was measured in some only of the runs. There is a heavy coal traffic, and the trains are fully loaded going up, but nearly empty coming down.

From Paderborn to Soest, the Compound takes 120 axles, the Ordinary 110.
,, ,, ,, Altenbeken ,, ,, 56 ,, ,, ,, 52.

TABLE 5.—*Consumption of Coal in Ordinary and Compound Goods Engines working the Newcastle York and Leeds heavy express on the North Eastern Railway in* 1886–87.

ORDINARY Goods Engines.				COMPOUND Goods Engines.				Saving by Compound Engines per mile.
Number of Engine.	Distance run.	Coal consumed.		Number of Engine.	Distance run.	Coal consumed.		
		Total.	Per mile.			Total.	Per mile.	
No.	Miles.	Cwts.	Lbs.	No.	Miles.	Cwts.	Lbs.	Lbs.
4	26,701	9,177	38·5	1301	26,081	8,180	35·1	3·4
22	27,609	9,758	39·6	1305	26,090	7,610	32·7	6·9
86	24,929	9,155	41·1	1309	23,051	7,210	35·0	6·1
152	22,110	7,785	39·4	1315	20,874	6,635	35·6	3·8
182	17,403	6,540	42·1	1323	18,985	6,085	35·9	6·2
360	20,642	7,225	39·2	1332	19,873	6,120	34·5	4·7
480	16,334	6,294	43·1	1336	16,622	5,075	34·2	8·9
539	10,735	4,544	47·4	1337	11,750	3,815	36·4	11·0
558	12,394	4,595	41·5	1338	12,543	4,020	35·9	5·6
667	8,033	3,155	44·0	1339	9,222	2,970	36·0	8·0
Totals and Means	186,890	68,228	40·9		185,091	57,720	34·9	6·0 *

* Mean saving 6·0 lbs. per mile, equal to $14\frac{1}{2}$ per cent.

TABLE 6.

Trial of Compound and Ordinary Passenger Engines between Heaton Junction and Tweedmouth on the North Eastern Railway.

January and February 1888.		Compound No. 18.	Ordinary No. 902.
Weight of twenty vehicles	tons	160	160
" " engine and tender	tons	81·35	71·70
" " train, total	tons	241·35	231·70
Mileage of engine, total	miles	960	952
" " train, "	miles	892½	892½
Coal consumption, total	lbs.	25,254	32,104
" " per engine-mile . .	lbs.	26·3	33·7
" " per train-mile . . .	lbs.	28·3	36·0
" " saving by Compound .	per cent.	21½	
Water consumption, total	gallons	19,383	24,155
" " per lb. of coal .	lbs.	7·68	7·78
Time of running, total	hrs. mins.	27 38	27 36
" " average per trip . .	hrs. mins.	1 58	1 58

Weather very rough, with boisterous wind and much snow, for Compound engine; and heavy wind for Ordinary.

TABLE 7.

Saving of Fuel by Compound over Ordinary Locomotives in trials made under the same conditions between Leipzig and Hof on the Saxony State Railways.

Eleven Compound Goods engines working at 180 lbs. per square inch, during four months' regular trial in 1887, showed a saving of 18 per cent. in fuel over similar Ordinary engines working at 135 lbs.

One Compound Express engine saved from 18 to 20 per cent. in fuel over a similar Ordinary engine with the same pressure, during three months' trial.

In a special trial, making four trips, the saving in water was 17 per cent. in a Compound over an Ordinary engine, with the same pressure and under the same conditions.

TABLE 8.

Comparative Consumption of Coal and Oil in Ordinary and Compound Passenger Locomotives on the Buenos Aires and Rosario Railway.

Four weeks from 27 May to 26 June 1887.	Distance run.	COAL.		OIL.	
		Total.	Per mile.	Total.	Per 100 miles.
	Miles.	Lbs.	Lbs.	Lbs.	Lbs.
Ordinary Engine, No. 10	3,937	111,001	28·19	595·24	15·12
Compound Engine, No. 34	3,638	81,350	22·36	599·65	16·48

Thus the Compound burnt 20½ per cent. less coal than the Ordinary engine, but used 9 per cent. more oil; the actual money saving was 3 dollars 20 cents per hundred miles. The working pressure in the Ordinary engine was 150 lbs. per square inch, and in the Compound 160 lbs.

TABLE 9.

Comparative Consumption of Coal per mile in five Ordinary and one Compound Passenger Engine on the Buenos Aires and Rosario Railway.

1887.	Number of Engine.	May.	June.	July.	August.	September.	Average.
Working pressure in Ordinary engines 150 lbs. per square inch, in Compound 160 lbs.	No.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Ordinary Passenger Engines (150 lbs.)	29	30·90	30·12	33·07	30·87	30·05	31·00
	30	27·50	31·90	29·17	35·62	32·15	31·26
	31	32·64	33·00	42·01	31·54	23·95	32·63
	32	30·51	28·63	28·95	34·17	32·82	31·01
	33	23·56	22·81	25·26	27·11	28·24	25·40
	Average	29·02	29·29	31·69	31·86	29·44	30·26
Compound Passenger Engine (160 lbs.)	34	22·74	22·81	22·99	22·21	22·74	* 22·70

* The saving of 7·56 lbs. per mile by the Compound is equal to 25 per cent.

TABLE 10.

Comparative Consumption of Coal by Compound and Ordinary Locomotives for three months ending 21 May 1886 on the Great Eastern Railway.

Number and Class of Engines.	1886. Four weeks ending	Distance run. Train Miles.	Distance run. Engine Miles.	Coal consumed. Total. Cwts.	Coal consumed. Lbs. per Train mile.	Coal consumed. Lbs. per Engine mile.
Eleven Compounds	26 Mar.	36,503½	37,794¼	9,849	30·2	29·1
Eleven „	23 Apl.	34,848¼	35,857¾	8,979	28·8	28·0
Eleven „	21 May	38,117¾	39,102¾	9,939	29·2	28·4
Totals and Averages .		109,469½	112,754¾	28,767	29·4	28·5
Six Ordinary .	26 Mar.	18,610	19,355½	5,724	34·4	33·0
Seven „ .	23 Apl.	23,761	24,362¼	7,162	33·7	32·9
Seven „ .	21 May	22,300	22,938½	6,661	33·4	32·5
Totals and Averages .		64,671	66,656¼	19,547	33·8	32·8
Mean Saving by Compounds					**4·4**	**4·3**

TABLE 11.

Comparative Consumption of Coal and Evaporation of Water by Compound and Ordinary Locomotives working passenger train from London to Norwich on the Great Eastern Railway.

October 1886.		4 Oct. Compound No. 704.	18 Oct. Ordinary No. 565.
Coal consumption, total	lbs.	2,780	3,444
„ „ per mile	lbs.	24·3	30·2
Water evaporation, total . . .	gallons	2,196	2,853
„ „ per lb. of coal . .	lbs.	7·9	8·2
Feed water, average per five minutes	gallons	112·5	126·4
„ „ temperature . . .	Fahr.	64°	65°
Average steam pressure per square inch .	lbs.	138	122
Load, London to Ipswich . .	vehicles	14	15
„ Ipswich to Norwich . .	vehicles	6	7

The Compound steamed freely, weather very favourable.

The Ordinary engine steamed moderately, weather rather unfavourable.

TABLE 12.

Comparative Consumption of Coke in Ordinary and Compound Locomotives on the Manchester Bury Rochdale and Oldham Tramways.

Coke consumption per mile by Ordinary engine .	10·3 to 10·9 lbs.
,, ,, ,, ,, ,, Compound ,, .	8·2 to 8·7 lbs.
Saving per mile by Compound engine . . .	2·1 to 2·2 lbs.
Percentage saving ,, ,, . . .	21 per cent.

The time occupied in running each day is $12\frac{1}{2}$ hours, and the distance run daily is 48 miles, which is done in seven trips of 6·7 miles each, with 40 minutes relief between each trip. The amount of oil served out is the same for both engines, namely 2 pints of lubricating oil and $\frac{1}{4}$ pint of valve or cylinder oil.

TABLE 13.

Comparative Cost of Repairs of ten Ordinary and two Compound Locomotives working between Hannover and Minden on the Prussian State Railways.

		Ten Ordinary Nos. 1111–20	Two Compound Nos. 1121–22
Distance run up to last repairs, total .	miles	883,884	185,609
Cost of maintenance, total . .	shillings	122,048	24,163
,, ,, ,, per mile run .	penny	1·66	1·56
Saving by Compound engines . .	per cent.		6

The Ordinary engines work at 146 lbs. pressure, and the Compounds at 176 lbs. Both classes are doing the same kind of work, and both have been running about four years. The cost of maintenance includes general repairs and renewal of tires. The Compounds save 15 to 20 per cent. of fuel and water as compared with the Ordinary engines.

TABLE 14.—*Steam Distribution in Compound Goods Locomotive on Entre-Rios Government Railway.*

Plate 25, Figs. 5 and 6.	HIGH-PRESSURE CYLINDER.								LOW-PRESSURE CYLINDER.								Plate 25, Figs. 5 and 6.
	LEAD. *f* full. *b* bare.		CUT-OFF in percentage of stroke.			RELEASE in percentage of stroke.			LEAD. *f* full. *b* bare.		CUT-OFF in percentage of stroke.			RELEASE in percentage of stroke.			
	Front port.	Back port.	Front port.	Back port.	Difference.	Front port.	Back port.	Difference.	Front port.	Back port.	Front port.	Back port.	Difference.	Front port.	Back port.	Difference.	
Forward gear.	Inch.	Inch.	P.c.	P.c.	P.c.	P.c.	P.c.	P.c.	Inch.	Inch.	P.c.	P.c.	P.c.	P.c.	P.c.	P.c.	Forward gear.
	0	0	74	70	4	89	88	1	0	0	77½	73½	4	94	93	1	
	0	0	70	67	3	88	86	2	0	0	74	70	4	93	92	1	
	1-64	1-64	60	57	3	83	81	2	0	0	66	62	4	90	89	1	
	1-16	1-16	50	48	2	78	77	1	1-32	1-32	56½	54	2½	87	86	1	
	f 1-16	*f* 1-16	40	41	1	74	73	1	1-16	1-16	50	49	1	83	82	1	
	f 1-16	*f* 1-16	30	32½	2½	68	68	0	*b* 1-8	*b* 1-8	40	42	2	80	79	1	
	3-32	3-32	20	22	2	60	60	0	1-8	1-8	27½	29	1½	75	74	1	
Mid.			5	5	0						7	7	0				Mid.
*Back gear.	3-32	1-8	20	28½	8½	61	64	3	1-8	5-32	11	17	6	65	67	2	*Back gear.
	f 1-16	*b* 1-8	30	39	9	68	70	2	1-8	5-32	20	30	10	72	74	2	
	f 1-16	*b* 1-8	40	49	9	74	76	2	*b* 1-8	*f* 1-8	30	41	11	79	79	0	
	1-16	3-32	50	56	6	79	79	0	*b* 1-8	*f* 1-8	40	49	9	82½	83	½	
	1-64	1-16	60	64	4	83½	84	½	1-32	1-16	50	57	7	86	86	0	
	0	1-64	70	72	2	88	88	0	0	1-32	63	67	4	89½	89	½	
	0	0	75	77	2	90½	90	½	0	0	70	72½	2½	92½	92	½	

* For backward gear the full-gear notch is the only one cut in the sector.

TABLE 15.—*Steam Distribution in Compound Tank Locomotive with Walschaert valve-gear on the Alsace and Lorraine Railway.*

Throw of Eccentrics 7·87 inches. Angle of advance 0°.
Length of Connecting-rod 88·19 inches.

See Plate 25, Figs. 7 and 8.	HIGH-PRESSURE CYLINDER. 14·76 ins. diam. × 19·69 ins. stroke. Outside Lap 1·30 inch. Inside Clearance 0·26 inch. Width of Ports 11·42 inches.						LOW-PRESSURE CYLINDER. 21·65 ins. diam. × 19·69 ins. stroke. Outside Lap 1·15 inch. Inside Lap 0·00 inch. Width of Ports 16·54 inches.					
	Travel of Valve.	Lead.	Maximum Opening of Steam Port.	Percentage of stroke. Cut-off.	Release.	Compression.	Travel of Valve.	Lead.	Maximum Opening of Steam Port.	Percentage of stroke. Cut-off.	Release.	Compression.
	Ins.	Inch.	Inch.	P.c.	P.c.	P.c.	Ins.	Inch.	Inch.	P.c.	P.c.	P.c.
Forward Gear.	2·48	0·12	1·18	72½	90	95	2·40	0·08	1·26	77½	94½	94½
	2·82	0·08	1·52	76	89	94	2·76	0·04	1·61	79	93	93
	2·34	0·12	1·04	68	88	94½	2·22	0·08	1·08	74	93	93
	2·60	0·08	1·30	72	88	93½	2·52	0·04	1·38	76½	92½	92½
	2·07	0·12	0·77	58½	84	92	1·97	0·08	0·98	65	91	91
	2·26	0·08	0·96	63½	84	91	2·19	0·06	1·04	69	89½	89½
	1·83	0·12	0·53	47	78½	89	1·71	0·06	0·96	53	86½	86½
	1·95	0·08	0·65	51½	78½	88	1·87	0·08	0·98	58	86	86
	1·75	0·12	0·45	39	74	86½	1·57	0·06	0·83	44	84	84
	1·79	0·08	0·49	43	74	85	1·65	0·08	0·91	49½	83	83
	1·60	0·12	0·29	28½	67	81	1·44	0·06	0·59	33	77	77
	1·61	0·08	0·31	30	67	80	1·48	0·08	0·67	37	77	77
	1·52	0·12	0·22	20	60	76½	1·32	0·06	0·35	21	70	70
	1·50	0·08	0·20	19½	59½	74½	1·38	0·08	0·47	26	71½	71½
	1·44	0·12	0·14	11	50	67	1·26	0·06	0·24	9½	57½	57½
	1·42	0·08	0·12	8	48½	65	1·30	0·08	0·31	11	61	61
Backward Gear.	1·44	0·12	0·14	12½	52½	72	1·22	0·04	0·16	10½	61½	61½
	1·42	0·08	0·12	9	50	67½	1·28	0·12	0·28	11	61½	61½
	1·52	0·12	0·22	22	64	79	1·28	0·04	0·28	20	71	71
	1·50	0·08	0·20	19	59	74½	1·36	0·12	0·43	22	70	70
	1·61	0·12	0·31	33½	72	84½	1·38	0·04	0·47	33	78½	78½
	1·60	0·08	0·29	29	66½	80	1·48	0·12	0·67	34½	77	77
	1·73	0·12	0·43	43	76½	87	1·48	0·04	0·67	44	82½	82½
	1·71	0·08	0·41	38	71	83	1·61	0·12	0·87	44½	81	81
	1·87	0·12	0·57	53	81	90	1·63	0·04	0·89	54½	85½	85½
	1·85	0·08	0·55	47½	76½	87	1·77	0·14	0·98	54½	85	85
	2·09	0·12	0·79	64½	86	92½	1·85	0·04	0·98	66	90	90
	2·07	0·08	0·77	58½	81	89½	2·03	0·14	0·98	64½	89	89
	2·40	0·12	1·10	73	90	95	2·17	0·04	1·02	75	92½	92½
	2·36	0·08	1·06	66½	86	92½	2·34	0·16	1·20	73½	92	92
	2·64	0·12	1·31	77½	91½	96	2·40	0·04	1·26	79	94	94
	2·60	0·08	1·30	72½	88	93½	2·58	0·16	1·44	77½	93	93

TABLE 16.—*Steam Distribution in Compound Locomotive on the Santa Fé and Cordoba Great Southern Railway.*

Angle of Eccentrics from crank, forward 60½°, backward 61½°.

Boiler Pressure 170 lbs.

See Plate 25, Figs. 9 and 10.		HIGH-PRESSURE CYLINDER. 16 ins. diam. × 24 ins. stroke. Clearance in link, top 0·94 inch, bottom 0·31 inch. Slip of die, top 0·81 inch, bottom 0·69 inch. Stroke in mid gear 2·63 inches. Outside Lap 1·12 inch. Inside Clearance 0·25 inch. Width of Ports 12·87 inches. Length of lifting link 14·06 ins.					LOW-PRESSURE CYLINDER. 23 ins. diam. × 24 ins. stroke. Clearance in link, top 0·31 inch, bottom 0·94 inch. Slip of die, top 0·81 inch, bottom 0·62 inch. Stroke in mid gear 2·56 inches. Outside Lap 1·12 inch. Inside Lap 0·00 inch. Width of Ports 17·00 inches. Length of lifting link 14·64 ins.				
	Notch in sector.	Travel of Valve.	Lead.	Maximum Opening of Steam Port.	Percentage of stroke. Cut-off.	Percentage of stroke. Release.	Travel of Valve.	Lead.	Maximum Opening of Steam Port.	Percentage of stroke. Cut-off.	Percentage of stroke. Release.
		Ins.	Inch.	Inch.	P.c.	P.c.	Ins.	Inch.	Inch.	P.c.	P.c.
Forward Gear.	Full	4·19	0·02	1·00	73¾	89½	4·50	0·03	1·16	78	93¾
			−0·02	0·94	72¼	88½		0·03	1·09	77½	94
	5	3·81	0·03	0·81	68	86½		0·00	1·03	73	92
			0·03	0·75	66	85		0·01	1·00	72¼	92
	4	3·50	0·06	0·63	61¼	83¼		0·03	0·87	67¼	90
			0·06	0·62	58½	81½		0·06	0·87	66	89¾
	3	3·19	0·09	0·47	52¼	78¾		0·07	0·87	60¼	87¼
			0·10	0·47	49	76¾		0·09	0·87	57¾	86½
	2	2·97	0·12	0·34	41½	73½		0·09	0·84	51½	83½
			0·13	0·37	38½	70¾		0·10	0·86	48½	82¾
	1	2·72	0·13	0·24	29½	66¾		0·12	0·72	40	79¼
			0·16	0·28	27½	63		0·13	0·74	37¾	78
Backward Gear.		2·91	0·10	0·38	37½	69¼		0·12	0·62	27¼	70
			0·12	0·28	31	68½		0·16	0·61	22	70¼
		3·09	0·09	0·47	47	75¼		0·09	0·72	36¾	75¾
			0·10	0·38	42½	75½		0·16	0·69	31¾	77
		3·37	0·06	0·62	55¾	79¾		0·09	0·84	47½	81
			0·09	0·51	53¼	81		0·13	0·78	43¾	82½
		3·62	0·03	0·74	62¾	83¾		0·06	0·87	55½	85
			0·07	0·62	61¾	84½		0·12	0·87	53½	86½
		3·87	0·00	0·87	69¼	86½		0·01	0·87	63¾	88
			0·03	0·75	68¾	87½		0·07	0·87	62¼	89¼
	* Full	4·26	0·03	1·07	74	89¼	3·91	0·03	0·87	68½	90½
			0·00	0·95	74½	90½		0·03	0·87	69¼	91¾

* For backward gear the two full-gear notches are the only two cut in the sector.

Discussion.

Mr. SAMUEL W. JOHNSON, Member of Council, being unable to attend the meeting, wrote that he had had no experience with compound locomotive engines, but had watched with considerable interest the records of the working of the Webb and Worsdell compounds, the results of which he thought were such as were likely to be obtained by the use of a higher boiler-pressure and a higher degree of expansion. He had not yet seen any records of trials made in this country between simple and compound engines where equal boiler-pressures and the same kind and quality of fuel had been used, and where the engines had been capable of taking the same maximum load; and to his mind comparisons made on other bases than these were of little value. With regard to the experiments made by Mr. Adams on the London and South Western Railway with both Mr. Webb's and Mr. Worsdell's compounds, in neither case had he been able to arrive at any satisfactory conclusion; and he thought it would afford valuable information if these experiments could be continued until something definite was arrived at.

The saving of fuel by the compounds was given at 15 per cent. Some three years ago he had made a number of locomotive boilers to work at a pressure of 160 lbs. per square inch, and had employed the engines on the same duties as those working at 140 lbs. per square inch; in every other respect the engines were of the same class. The result had at once been a saving of fuel of from 11 to 13 per cent. with the higher pressure, a saving almost directly in proportion to the increase of $14\frac{1}{4}$ per cent. in the boiler pressure. From the 20 lbs. increase in pressure no inconvenience whatever had been experienced in any of the working parts of the engines—cylinders, valves, rods, or bearings. He had no prejudice either in favour of or against any particular design of engine, providing it was suited to the work it had to perform; and he should be in favour of any engine which could be proved to do an equal amount of mechanical duty to an ordinary engine, with a smaller amount of fuel and at a lower aggregate cost.

The question arose, how far could the ordinary boiler-pressure of 140 lbs. per square inch in the simple engine be increased with advantage, and without inconvenience in working; and to what extent had the compound engine an advantage, if any, over the simple engine. It must be admitted there were several good points about Mr. Webb's compound engine:—firstly, it got rid of outside coupling-rods; secondly, the fire-box and grate area could be made as large as could be wished; thirdly, there was only a single-crank axle, instead of a double one. But on the other hand there were three cylinders and three sets of motion to do the work, instead of two, involving a consequent increase of friction owing to increased number of parts.

As a specimen of the working of heavy fast main-line passenger trains on the Midland Railway, the results from a number of engines over a considerable period on the Carlisle section showed a consumption of 29·3 lbs. of fuel per train-mile with an average load of $13\frac{3}{4}$ vehicles, and 30·1 lbs. per train-mile on the Leicester and London section with an average of $14\frac{1}{4}$ vehicles: using in each case the ordinary coal of the district. The booked speeds of these trains were from 48 to 50 miles per hour; and the coal used included that for getting up steam, standing &c., in fact all coal booked to the engine. The published consumption of Mr. Webb's large compounds on similar duties he believed was 29·5 lbs. per train-mile.

Mr. David Banderali mentioned that on the Northern Railway of France a compound goods engine had now been in use for about a year, having four cylinders in two tandem pairs on the Woolf plan, and there had been found to be a saving in fuel of certainly something like 12 per cent. with the same boiler pressure, while at the same time the engine was able to pull heavy trains up steep inclines more easily.

In reference to the spark-arrester mentioned in page 94 of the paper, he should like to know whether there was any inconvenience arising from its being placed in the smoke-box, and whether it did not interfere with the good working of the blast-pipe. In the compound engine he had generally found that there was some

(Mr. David Banderali.)

difficulty in getting a sufficient blast in the chimney; and if there was an extra spark-arrester in the smoke-box he was afraid it would produce a bad effect in impairing the power of the blast-pipe.

It was further stated in page 95 that "by compounding existing engines without increasing their pressure an economy of only from 10 to 15 per cent. may be obtained." This seemed to him to be an answer to a question raised by Mr. Johnson; and he thought there was an economy of fuel to be expected from compounding existing engines, because this had been found to be the result in the trials on the Northern Railway of France.

In regard to the capacity of the receiver or reservoir, which it was stated in page 96 should be at least equal to that of the high-pressure cylinder, he had found that the capacity should be a little larger than that. In an express compound engine with four cylinders, not on the same plan as the tandem already mentioned, he had found that the capacity of the reservoir must be something like half as large again as the joint capacity of the two high-pressure cylinders, instead of only equal to it.

On the Northern Railway of France there were now three compound engines; one was the express passenger engine just mentioned,* having two high-pressure cylinders inside and two low-pressure outside; and another was the tandem goods engine having two cylinders on each side, the low-pressure one in front of the high-pressure, with the same motion and only one treble-ported slide-valve for both cylinders.† They had also been trying for six months a mixed engine for goods and passenger trains, having six wheels coupled and three cylinders. While there had certainly been found a saving of fuel in the use of all these compound engines, the question was whether against that saving of fuel there was any extra expense in working the engines. Of course this was a question of experience; but as far as concerned the working of the engines now mentioned, hitherto there had not been found in wear and tear any extra expense that might not be diminished by further practice.

* See description in the "Revue générale des Chemins de fer," May 1887, page 263. † Ibid, November 1888, page 285.

There had been sometimes a little more expense for oiling the engines; but this had been traced partly to some special causes independent of the compound system, and partly to the bad practice of some of the drivers, who were apt to use too much oil by supplying it into both the high-pressure and the low-pressure cylinders. It was not necessary to oil the steam everywhere, and a very good result had now been found from oiling it in the regulator as it left the boiler; this was quite enough for oiling three or four cylinders.

The President enquired how the cylinders were arranged in the three-cylinder engine of which Mr. Banderali had spoken.

Mr. Banderali replied that the engine had an inside cylinder in the middle for the high pressure and two outside cylinders for the low pressure. The difference between that arrangement and Mr. Webb's was that the French engine had three coupled pairs of wheels, and all three cylinders acted together on only one pair of wheels. The engine had ample starting power.

Mr. William Schönheyder observed that the two kinds of compound locomotives which were practically known in this country were those of Mr. Webb and Mr. Worsdell. The former had been the first to be tried to any considerable extent, the endeavour being to arrange a compound engine in such a manner as to do away with coupling-rods, which were considered by Mr. Webb to be a very great objection. That had been done by arranging a low-pressure cylinder to work on one axle by itself, and two high-pressure cylinders to work on another axle. To what extent it was really worth while to do away with coupling-rods, in comparison with the disadvantages which their use entailed, was doubtless best known by locomotive superintendents; but at any rate coupling-rods were used at the present time to a great extent all over the world, and little or no objection was felt to them if they were made sufficiently strong. Of course they necessitated two or more pairs of wheels travelling at the same number of revolutions, whether they

(Mr. William Schönheyder.)
were all exactly the same diameter or not; and this certainly was a great disadvantage. But on the other hand the objections to the Webb compound were, firstly that there were three cylinders with three sets of valve-gear to make and look after and maintain; and secondly that there were two distinct sets of reversing gear. The latter he believed were now generally coupled, while there was also the means of working them separately. Moreover as the strength of a chain was the strength of its weakest link, the power of starting could not be taken as any greater than whatever was the smallest power of the engine at any time; and whenever the low-pressure piston happened to be at or near the end of its stroke, there was only the power of the small cylinders to start with. That was an occurrence which he knew frequently happened, for he had several times been in trains on the London and North Western Railway when the engine had had to be backed in order to start the train; once last summer a passenger train had to be backed three times from Rugby station before the engine could start. Then there was the discomfort to passengers, of which locomotive engineers might perhaps think but little, that on starting they experienced unpleasant jerks forwards and backwards for a considerable time, before the train got into full swing and a uniform driving power was attained; he had experienced this both on the main line of the London and North Western Railway and also on the underground line, and he had no doubt that others had experienced it also.

The two-cylinder compound locomotive of Mr. Worsdell appeared to him to be a much better arrangement; because it was a much simpler engine, with only two cylinders as in the ordinary locomotive, and only two sets of valve-gear. Although a special starting or intercepting valve was used, he believed it was not necessary, and that an intercepting or starting valve could be arranged in such a manner that only the two ordinary handles should have to be attended to, namely the regulator handle and the reversing lever. It thus made a much simpler engine. Nor was there any difficulty in getting a low-pressure cylinder of sufficient size, because even if this could not be managed with inside cylinders it could be done with outside cylinders, although he believed Mr. Worsdell got all

the power he wanted with his present inside-cylinder arrangement; and there need be no objection to outside cylinders in a locomotive on the score of unequal balancing, because it was a simple matter to make the two pistons of the same weight, and all the rest of the working gear, piston-rods, slide-rods &c., were of the same dimensions for both cylinders. In this two-cylinder arrangement the coupling-rods were retained, and no difficulty was found with them; many engineers he believed would say the same.

With reference to the proportion of the cylinders, it appeared to him that the practice of locomotive engineers in designing a compound engine had been to start with the size of the high-pressure cylinder; whereas they ought in his opinion to start with the size of the low-pressure cylinder. In designing a compound locomotive to work with the same boiler pressure and the same number of expansions as a simple engine, the low-pressure cylinder should be made of the same capacity as the combined capacities of the two cylinders in the simple engine; and after this had been done, the high-pressure cylinder should then be proportioned to whatever size was best in practice. In locomotive practice it would probably be necessary to make the high-pressure cylinder rather larger than one of the single cylinders in an ordinary locomotive, in order to get sufficient propelling power at starting. But the size of the high-pressure cylinder could be varied within large limits without materially affecting the total power exerted by the engine, although thereby affecting the economy and the initial strains on the working gear of the two cylinders.

Referring to the indicator diagrams exhibited, it seemed to him useless to show diagrams combined in that manner, because it was impossible to tell from them whether the steam was doing its proper relative duty in the two cylinders. In each instance the low-pressure diagram ought to be shifted further towards the termination of the stroke; and it would then be found that the toe of the low-pressure diagram would most probably touch the theoretical expansion curve as continued from the high-pressure diagram. (See Proceedings 1879 page 359, and 1887 page 64.)

Mr. JAMES HOLDEN said the Great Eastern Railway had now twelve compound engines, eleven of which were passenger express engines, with 7-feet coupled driving wheels, and cylinders 18×24 inches high-pressure and 26×24 inches low-pressure; and one was a goods engine, with six coupled wheels of 4 feet 10 inches diameter, and cylinders of the same size as those of the passenger engines; all had a boiler pressure of 160 lbs. per square inch. There had been no difficulty whatever in maintaining steam, although the blast was naturally very soft. Except just at first, there had been no difficulty in manipulation; just at the very outset there had sometimes been a little difficulty, arising probably from nervousness on the part of the drivers. Going out from Liverpool Street there was an ascending incline of 1 in 70 to go up, half a mile long, with a stop signal in the middle; and sometimes when that signal was against the drivers, before they were thoroughly accustomed to the compound engines, they would slacken speed in order not to be brought to a stand, and would bring the engine so nearly to a stand that at last they would be afraid it would come entirely to a stand; and they would then admit the boiler steam direct into the low-pressure cylinder, with the result that they sent the wheels spinning round, just doing what they were trying to avoid. But that objection had now been entirely overcome, and he did not know of an instance, for the last two years at any rate, where anything of that kind had occurred. It was a very natural result in the early stages, when the men had had no experience of any compound engine, and had everything to learn.

With regard to economy, as compared with sister engines built exactly the same in every respect—except in being non-compound instead of compound, and with a boiler pressure of only 140 lbs. instead of 160 lbs., and a single pair of leading wheels instead of a bogie—the economy of fuel in favour of the compounds had been about 14 per cent., and the economy of water about 8 per cent. In respect of wear and tear, so far as he was aware there was no difference whatever between a compound and a non-compound, with the possible exception of the pistons, which had at first been constructed without tail rods, and there had then been a slight wear

upon the bottom side of the low-pressure cylinders at their front end; but since the piston-rods had been carried through, there had been no difficulty whatever in that respect. There was also no increase in the quantity required of small stores, such as oil and tallow; and as far as he was aware there was no extra expense of any kind in working the compounds. There had been a little difficulty with the fire-box stays in some of the compound engines; but he did not attribute that at all to the system of compounding, which could not have anything to do with it. Nor were the boilers in any sense the worse for wear, except the ordinary wear and tear corresponding with their mileage. But on this account the working pressure had been reduced from 160 lbs. to 140 lbs., with the result that the comparative saving in the fuel had thereby been reduced from 14 to only 2 per cent.; which led him to think that it was necessary in compounding to employ a higher pressure probably than could be economically used in the non-compound engine with the short stroke to which a locomotive was limited. At the present time he was building boilers to work at a pressure of 175 lbs. per square inch; and he also purposed putting one boiler at least, if not two, to work at 175 lbs. in non-compound engines, so as to arrive by actual experiment at the relative value of compounding and non-compounding when working at the same boiler pressure, as regarded both traction and maintenance.

Mr. ARTHUR PAGET, Vice-President, enquired whether Mr. Holden's engines had any special starting valve or other special arrangement for starting.

Mr. HOLDEN replied that the whole of the engines were fitted with the Worsdell and v. Borries starting valve. They were the original engines built by Mr. Worsdell, excepting only the goods engine which had since been constructed by himself.

Mr. ALEXANDER McDONNELL considered that theoretically the compound system ought to be an economical mode of using steam;

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but he thought more information was required as to the wear and tear of the compound engines, and particularly of the boiler, which might be more expensive than the old boiler. He could not imagine that two or three or four cylinders with their necessary gear could be as economical as one pair of cylinders. With regard to coupling-rods, he had not found that when properly constructed they were attended with much disadvantage, and had not experienced much difficulty with them, and he had therefore never objected much to them; but of course, if they could be got rid of without any consequent disadvantages, it would be desirable to do away with them. There was a great deal more economy, he thought, to be effected upon railways by other means besides compounding the engines; and it would be quite as useful for railway engineers to turn their attention to those other means as to pay so much regard to the question of compounding, particularly in this country. But the compound system should not be neglected, merely because it might not suit in England where the price of coal was low; for it presented of course certain advantages which might be obtained in other countries where the price of coal was much higher than in England.

It should be remarked that nearly all the experiments had been made upon compound engines working under circumstances well adapted to show their economy. A compound locomotive would work advantageously if it was working with a heavy uniform load; but the same engine might not work so economically with a small load or at a low speed. Having once built some goods engines with 18-inch cylinders instead of the ordinary standard 17-inch cylinders, in the expectation of getting a better result, he had not succeeded in doing so; indeed the result was not quite satisfactory; and the reason was that, although the 18-inch cylinder engines worked economically with a heavy load, they did not work economically with a light load. In this country a locomotive was hardly ever working continuously with its full load. An engine would start with fifty wagons, but before reaching the end of its journey it might have no more than ten. The average load of an engine was seldom much more than half its maximum load. Therefore an engine, which, if it was

working the whole time with a maximum load, would be economical, might not be economical if working part of its time with a small load. An engine had to take its turn with slower trains and lighter loads; and when it got to be an old engine it had to go on branch lines and work there. Therefore figures like those given in the paper ought to be received with a certain amount of caution, not because they were not reliable when the circumstances were understood under which they were arrived at, but because those circumstances did not cover all the ground required. The further information however that he desired with regard to the wear and tear of the compound engines could not be expected without a longer experience extending over a series of years. It would be better, he thought, for those who advocated the compound system to admit at once that there must be a greater expense attending it in first cost. Whether it was wise to incur that greater expense or not, he did not know; but with three cylinders, and additional starting gear, and various kinds of safety-valves, and other special contrivances, the cost must be higher, although the extra expense might not be serious.

The PRESIDENT asked if Mr. McDonnell could give his experience as to what had been the actual disadvantage of the larger 18-inch cylinders which he had substituted for 17-inch cylinders in ordinary locomotives. Had it come within his own experience that the employment of higher pressures in simple engines had effected like economies to those claimed for the compound locomotive?

Mr. McDONNELL replied that the information he had to give on those points was rather at second hand. The Great Southern and Western Railway of Ireland had worked express passenger trains from Dublin to Cork with engines having 17-inch cylinders and 22-inch stroke and 140 lbs. boiler pressure. After he left that line some passenger engines had been built by Mr. Aspinall of exactly the same kind, but with a boiler pressure of 160 lbs. These two classes of engines were working trains very well adapted to show economy in such a case, because they were always working express

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passenger trains and nothing else; they were working with a uniform load at a high speed, and therefore exerting a considerable amount of power. They ran from Dublin to Cork, 165 miles, in something under four hours, with three stops, one of ten minutes, so that the speed was good; and they had an average load of $10\frac{1}{2}$ carriages, carrying the American mails. He was informed by Mr. Ivatt, the present locomotive engineer of the railway, that in June, July, and August 1883 the engines with the lower pressure worked with a consumption of Welsh coal varying from $25\frac{1}{2}$ to $26\frac{1}{2}$ lbs. per train-mile. In June, July, and August 1884 the new engines with 20 lbs. more boiler pressure worked the same trains with an average consumption of about 4 lbs. less of coal. The whole of this economy was not attributed by Mr. Ivatt to the increased pressure, as he thought there were other things which partly caused the economy, such as a rather larger blast-pipe &c. That was a very good experiment as showing the saving consequent on the higher boiler pressure. In the case he had previously mentioned, the 18-inch cylinder engines had been working goods trains; and goods engines, although working economically at a full load, were not working economically at a light load, and such engines were necessarily working at a light load for part of their time.

Mr. JOHN G. MAIR, Member of Council, thought rather a better result would have been got out of some of the compound engines, if their heating surface and grate surface had not been contracted as they seemed to be. For from Table 11 it appeared that on the Great Eastern Railway the evaporation of the compound engine there referred to was only 7·9 lbs. of water per lb. of coal, while with the ordinary engine it was 8·2 lbs. of water per lb. of coal. He should therefore like to know what the relative heating surfaces and grate areas were in the two engines there compared.

Mr. WORSDELL replied that they were exactly the same in the two engines.

Mr. MAIR thought that, the heating surfaces being exactly the same in both cases and the grate surfaces also the same, it seemed

rather anomalous to get a smaller evaporation of water per lb. of coal in the compound engine where there was less water to evaporate, than in the other engine where there was more water to evaporate. It had been stated by Mr. Holden (page 124) that the saving of fuel in the compound had been about 14 per cent., while the saving of water had been only about 8 per cent. Hence he should have inferred that the rest of the 14 per cent. saving in fuel must be due to the better evaporation obtained in the compound; but this conclusion did not correspond with Table 11, where the evaporation seemed better in the ordinary engine than in the compound.

Mr. DRUITT HALPIN, referring to the recommendation in page 96 of the paper that the capacity of the intermediate receiver should be at least equal to that of the high-pressure cylinder, thought the larger the intermediate receiver could be got, the better, provided it could be got larger without paying extra for it in one way or another. Apparently the only price to be paid for it in the compound locomotives shown in the drawings was that of the extra cast-iron pipes in the smoke-box, of which material he did not approve for locomotives; but it had not here to be paid for in the sense in which it often had to be paid for in other engines, namely by radiation or loss of heat. In fact the reverse was here the case: a drying of the steam was obtained, which was exceedingly useful; and therefore the larger the receiver could be got, the better would the results be in all such engines. With regard to Mr. Banderali's remarks (page 120) about the receivers in his Woolf engines, in these, as in similar tandem marine engines, it was much better he believed to have only one large receiver, instead of trying to carry out the Woolf system in an indirect way with exhaust and steam passages which were too long to be passages and too short to form receivers. By simply putting one large common cylinder to serve as a receiver between the two high-pressure cylinders, and letting them both exhaust into that, and also letting the two low-pressure cylinders draw out of that again, much more uniform and favourable results would be obtained.

In page 90 reference was made to the means adopted for rendering

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the work equal in both cylinders, by altering the length of the lifting links or altering the angle of the levers on the reversing shaft. That was a well-known plan, which had been used long before anything had been said about compounding locomotives. It was used largely on the Clyde in marine engines, in which a uniform distribution of power was effectively obtained by simply altering the angle of the levers or the length of the links.

As to the blows on the cranks and crank-pins being less severe in the compound engine (page 86), this he considered was a matter of degree. In fast-running engines with 30-inch cylinders he had plotted the effect out in the form of a diagram for a speed of 50 miles an hour, and the result had distinctly been that in that particular instance there was no blow at all; on the contrary the crank was pulling the piston at starting, in consequence of the inertia of the piston and rods being so great. In those fast-running locomotives therefore the inertia came in very materially to modify the supposed blows on the cranks.

The relative advantages or otherwise of two or three-cylinder compound engines constituted a large question, and there was a great deal to be said on both sides. One fact however should not be lost sight of, although unfortunately the accurate data available in regard to it were limited. With simple two-cylinder engines, having four wheels coupled, experiments had been made by the late locomotive superintendent of the Eastern Railway of France, M. Regray, with the greatest possible care and with the best apparatus; and the result arrived at was that, out of 100 I.HP. in the cylinders, 43 HP. only was available on the draw-bar. The loss of 57 per cent. was rather a high price to pay for the efficiency of the engine. How much of that loss was due to coupling-rods no one could yet say; but a considerable amount of it must be due to the rods, because it was known that large engines with a single pair of driving wheels not coupled were doing their work more economically, while advanced locomotive engineers who had not yet gone in for compounding were at any rate going back to the single pair of driving wheels. Moreover that astonishing loss of 57 per cent. had been confirmed independently on the Pennsylvania Railroad, in trials made with an

engine having $18\frac{1}{4} \times 24$ ins. cylinders and 6 ft. 6 ins. wheels four coupled; by taking indicator diagrams up to 65 miles an hour, which were professed to be taken correctly, the power on the draw-bar was found to be only 42 per cent. of that in the cylinders, or only 1 per cent. less than in the French experiments. It was therefore an open question, on which it was much to be desired that information could be given, as to what the actual loss was by the coupling-rods. It would never be solved, he believed, by trials made on the road; there was no other way of getting at it, he thought, than by the method followed by M. Borodin (Proceedings 1886, page 298), which unfortunately however had not been carried far enough for this particular purpose :—namely by running the engine stationary in the shed, and absorbing the power by a brake, and measuring the results accurately. That was the direction in which he thought engineers should go, analysing the engine piece by piece to ascertain the friction, as had been shown by Professor Thurston in a paper * lately read to the American Society of Mechanical Engineers, so that it might really be known where the loss of power occurred; because a loss of 57 per cent. was rather too much to pay for the working of the machine itself.

The indicator diagrams shown in Figs. 38 and 39, Plate 35, gave evidence of the old trouble of throttling the steam at the beginning of the stroke. After steam had been produced at high pressure in expensive boilers made with great care, there was then a loss of from 10 to 25 lbs. pressure on entering the cylinder, without any corresponding useful result. To attempt to force steam at abnormal speeds through small pipes was bad practice; and where, as in the case of the locomotive, there was no radiation, it was a matter of only a small extra cost of copper to make the steam pipes large enough, and the valves also large enough. When once steam had been made in the boiler at a pressure of 150 or 170 lbs., it should be used at that pressure without wire-drawing; he had not much faith in any advantage being obtained by superheating and wire-drawing. Similarly the back pressure shown in some of the high-speed

* "Engineering," January 1889, pages 22, 47, and 68.

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diagrams from the large cylinder denoted too small a size of the exhaust pipe for the speed; from one of the diagrams in Fig. 38 he had calculated that as much as 117 horse-power, meaning 5·95 lbs. of coal per mile, was lost in consequence, being absolutely wasted in simply pumping the steam out of the large cylinder and forcing it up the chimney. That was the loss at the bottom of the diagram alone: what it was at the top he did not know.

For the intercepting valves shown in the drawings he did not see the necessity; he was himself working in a different direction, and thought that in compounding he could obtain the desired result without much inconvenience. In Figs. 16 and 18, Plate 27, was shown a plan which he should certainly be afraid to trust. What guarantee was there that the two long slender rams R R, which had to slide in and out of their sockets whenever the valve worked, were kept tight under 175 lbs. pressure of steam? This he hardly thought could be done; and if they were leaking at all, there would be no knowing how much steam was going into the high-pressure cylinder and how much into the low-pressure, or how much was going through the high-pressure into the low-pressure.

The limit to the diameter of cylinder with which non-compound locomotives could be economically worked was a complicated question, because there were both advantages and disadvantages in the use of larger cylinders and higher speed. Not only was the knock or blow on the cranks greatly reduced by the increased inertia at higher speeds, but also the initial condensation and the condensation during expansion were likewise greatly reduced by the higher speeds at which engines with larger cylinders would have to run in order to work up to their full power.

Mr. THOMAS W. WORSDELL, Member of Council, referring to the remarks received from Mr. Johnson (page 118), did not doubt for a moment that there was an economy of fuel in the use of higher boiler pressure and larger cylinders in non-compound locomotives; but it required a good deal of further information to understand whether there was a real economy throughout the absolute work performed by engines which had a high initial pressure upon their pistons. For

instance, taking the boiler pressure of a non-compound engine at 170 lbs., and admitting this full pressure at once upon the piston, it would be continued to the point of cut-off, according to the amount of expansion required for the work to be performed. The exhaust steam remaining as back-pressure against the piston was from 5 to 10 lbs., according to the speed of the engine. Assuming it to be 10 lbs., there remained an effective pressure of 160 lbs. upon the piston, and through the piston upon the cross-heads, the gudgeons, the crank-pins, and the axles. This pressure, if the steam was used expansively to the best advantage, occurred only in the very early part of the stroke, and became therefore what was called a knocking or bumping pressure, admitted at the beginning of the stroke and cut off early. The compound engine, starting with the same initial pressure of 170 lbs., did not exhaust up the chimney the whole of the steam from the high-pressure cylinder as in the case of a non-compound engine, thus wasting it: the exhaust steam from the high-pressure cylinder was reserved in a receiver, in order then to be put into the larger low-pressure cylinder. Thus the high-pressure cylinder became part of the receiver, storing up its exhaust steam for the work of the low-pressure cylinder. According to the indicator diagram shown in Fig. 37, Plate 34, the exhaust or back-pressure in the high-pressure cylinder would be about 50 lbs.; and deducting that 50 lbs. from 170 lbs. would leave 120 lbs. actual effective pressure upon the working parts of the high-pressure cylinder, instead of the 160 lbs. effective pressure in the non-compound engine. Therefore there was less initial strain on the working parts in the compound engine. Moreover it was necessary in compounding to prolong the initial pressure a little further in the high-pressure cylinder, so as to get the lower effective pressure continued over a longer arc of the crank, trusting to the low-pressure cylinder for completing the ultimate expansion. In the latter cylinder the pressure was only 50 lbs. on admission, and this low initial pressure was therefore easily worked down by expansion to a comparatively low pressure at its release. Hence in his own opinion it required no immediate present experience to tell what must be the result of working those high pressures upon non-compound engines as compared with compound engines: they might

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result in a saving of fuel, and no doubt would do so; but whether there would be a saving in other respects was a matter which remained at any rate an open question, although he had no hesitation about the result himself. Mr. Webb had recently told him that his three-cylinder compound engines were equal to ordinary engines having a pair of 20-inch cylinders. But he certainly should not like to work a pair of 20-inch cylinders at the ordinary 140 lbs. initial pressure, cutting off at a small percentage of the stroke, as he knew quite well what the result would be: the engines would have to come into the shop in a very short time for repairs to the axle-boxes, for there would be so much knocking that they would want repairing very soon. As a matter of fact his compound engines had now been running for about three years, doing very heavy goods service and averaging over 45 loaded wagons daily for long journeys; they had not been in the shops for two years and ten months.

He had no wish at all to speak unduly favourably of the compound engine, having simply used it for the sake of the advantages which it appeared to him to present at the time when he happened to go from a railway where fuel was cheap to one where fuel was dear—more than double the price. Knowing that compound engines were receiving some attention abroad, and recently in this country from Mr. Webb, he began to reflect upon what he could do, although not in a position to go into the matter with such boldness as Mr. Webb could afford to do, because he was at that time a stranger upon another railway. Finding after calculation that there was a considerable chance of saving fuel by compounding, he thought it would be wise to make some experiments; and, as already mentioned by Mr. Holden (page 125), he made one compound locomotive for the Great Eastern Railway. It was at once found impossible to start the engine by the method ordinarily employed of simply admitting high-pressure steam into the low-pressure steam-chest. Having to face this difficulty with the engine already built, and having determined that the compound principle must be of some advantage, he had then to follow it out by introducing a starting valve similar to that shown in Plate 31: after which there was no difficulty whatever, the valve giving every facility for starting with the two-

cylinder locomotive. On the North Eastern Railway he had now 76 of these compound engines, and was still going on building them. With the same size of high-pressure cylinder there was the same facility for starting as in an ordinary locomotive, provided that the high-pressure crank was in a favourable position for starting. But if the high-pressure crank was on its dead centre, it became necessary to trust to the low-pressure cylinder for starting, which was done by simply admitting the boiler steam through a small pipe direct into the low-pressure steam-chest. At the same time the boiler steam had to be prevented from getting back to the exhaust side of the high-pressure piston; and hence the use of the intercepting valve. For this purpose Mr. v. Borries employed a disc valve working on a horizontal spindle; while he himself preferred a flap valve of the kind shown in Fig. 28, Plate 31. Immediately the intercepting valve was shut, the boiler steam entering through the small pipe passed down into the steam-chest of the low-pressure cylinder. As the low-pressure piston was double the area of the high-pressure, it was manifest that it could start much more easily; and the drivers were always glad when the low-pressure crank was in the starting position, because then the engine could always start more easily than with the other crank. The use of the intercepting valve or flap valve, according to either Mr. v. Borries' arrangement or his own, was quite necessary for preventing the boiler steam from getting back into the reverse end of the high-pressure cylinder through the exhaust port, and thereby blocking the piston. That might occur frequently, or it might occur very rarely; but it generally did manage to occur when the low-pressure crank was in an awkward position for starting.

He was very glad to hear Mr. Bandcrali's experience of compounding (page 119), because the whole subject of compounding was at the present time of the greatest interest. He was perfectly satisfied with what he had himself succeeded in doing so far, and he hoped to do a little better further on. He desired however to avoid changing the general style of the engine, while endeavouring in respect of economy to follow the marine engineers, who had done so much and in such a short time for the development of expansion. But in a locomotive engine, which had to carry itself from place to

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place at such a rapid speed, it was necessary to use the fewest possible parts, and to keep down the weight of the engine within the lightest possible limits, especially as it was not to be expected that the speed could be reduced as the weight of the trains increased; on the contrary the speeds unfortunately increased and the weights of the trains increased also. He thought therefore that he was justified in trying as far as possible to keep to the simpler arrangement of two cylinders in the compound locomotives, with a view to attain if possible the results that were desired. The compound bogie passenger engine shown in Plates 29 and 30 was able to take any reasonable train at any reasonable speed that might be required by any railway in this country. It was now running daily the Scotch express from York to Newcastle, and from Newcastle to Edinburgh. The 18-inch high-pressure cylinder and the 26-inch low-pressure were both of them inside cylinders; the stroke was 24 inches, and the driving wheels were 6 ft. 8¼ ins. diameter. The engine had no difficulty at all in running with a light or a heavy train, up to as heavy a train as it could take at the speed required: notwithstanding what had been said about the difficulty of doing both light work and heavy work with a compound engine. As a matter of fact the accelerated Scotch express running in August last had been taken by an engine of this class regularly the 124½ miles from Newcastle to Edinburgh, and alternately from York to Newcastle; the train had sometimes eight vehicles and sometimes nine, but averaged seven. The speed was very great, but no difficulty was experienced. The same engine was now running the express over a longer distance with twelve to fourteen carriages, proving that the compound locomotive was adapted to varying circumstances.

The PRESIDENT asked whether it was with a like economy that the compound engine took a light train and a heavy train.

Mr. WORSDELL replied that it was not so; the economy was dependent upon the work done, that is there was a greater saving with a heavier than with a lighter train. What he wished to correct was the impression that if the size of the cylinders were increased

the compound engine would be incapable of doing light work; on the contrary he maintained that it was capable of doing light work. But it was not so capable of running fast down hill, unless a special arrangement was provided for relieving the counter-pressure in the large low-pressure cylinder, which at that time offered a great resistance; a relief valve had consequently to be provided in the low-pressure cylinder to obviate that objection.

Not having paid much attention to the capacity of the steam reservoir between the high and low-pressure cylinders, he was unable to say how large it should be, but he believed the larger the better; and he therefore considered Mr. Banderali was right in making it 1½ times the joint capacity of the two small high-pressure cylinders in the four-cylinder express compound which he had mentioned (page 120).

The absence of the coupling-rods he had no doubt was a great advantage according to circumstances; but also according to circumstances their presence was no less a great advantage. For instance, if it were required to distribute a large amount of cylinder power through wheels of small diameter in order to obtain a great power of traction, it was necessary to have some means of coupling the wheels together; whence had arisen in this country the six-wheel coupled goods engines, and in foreign countries the eight-wheel coupled with very small wheels; for it was manifest that, if cylinders equal to the power required were set to drive only one single pair of wheels, it was not likely that sufficient adhesion would be obtained for propelling the load. At the Manchester exhibition in 1887 he had noticed an engine with eight wheels, of which six were driven, and with three cylinders on the principle of Mr. Webb, who had started with the idea that no coupling-rods were required. The two high-pressure cylinders were connected to one pair of wheels, which however was coupled to another pair; so that the two high-pressure cylinders drove two pairs of wheels, which themselves were 5 ft. 2½ ins. diameter. The low-pressure cylinder was connected to the third pair of wheels of the same size. As the low-pressure cylinder was generally understood to be about equal in power to the two high-pressure cylinders together, it was manifest there was an irregular

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distribution of tractive power upon the six driving wheels, the two high-pressure cylinders working upon four coupled wheels, while the low-pressure cylinder of equal power worked upon only one pair of wheels of the same size, not coupled with the others. There might be difference enough between the diameters of the cylinders to allow for some difference in the amount of traction; but at any rate the distribution over the three pairs of wheels could not possibly be as even as it should be. Moreover where the high pressure was divided into two cylinders, the starting power was certainly limited to that due to the one high-pressure cylinder only which was in the proper position for starting. There could be no doubt therefore that the two-cylinder engine had a greater starting power than the three-cylinder engine.

In regard to the indicator diagrams, he quite agreed with Mr. Halpin (page 131) that diagrams which showed any material amount of wire-drawing could not but be considered as denoting a wasteful use of steam. Wire-drawing was certainly shown in some of the diagrams exhibited: and he had also experienced the same defect himself, until he had altered the valves so as to get the best result possible from the two cylinders. In Fig. 34, Plate 33, which was a slow-speed diagram from a passenger engine at 10 miles per hour, it would be seen that the low-pressure cylinder started with even a higher pressure than the high-pressure cylinder left off at. The same was also shown in Fig. 35, which was taken at a higher speed of 50 miles an hour. The loss of initial pressure began here to be felt, because of the earlier cut-off in the high-pressure cylinder, in which also the compression was a little greater; and the consequence was that the loss between that and the low-pressure cylinder was likewise greater than in Fig. 34, as shown by the rather larger space between the high-pressure and low-pressure diagrams. In the return stroke of the low-pressure cylinder there was of course a certain amount of back pressure due to the higher speed, as shown in Fig. 35, which did not occur in the slow-speed diagram, Fig. 34.

With regard to the intercepting valve, for which it was considered by Mr. Halpin (page 132) that there was no need, he did not see how there could be anything more simple than the flap

valve shown in Fig. 28, Plate 31, or the disc valve shown in Figs. 11 and 13, Plate 26, which admitted through its spindle a jet of boiler steam to the low-pressure cylinder. Either of these seemed to him to be about as simple a form of intercepting valve as could possibly be got. And even in the valve shown in Figs. 16 and 18, Plate 27, all the parts were parallel, and could be turned or bored true and central; he had one of these valves working, and was satisfied with the result; there was no trouble with it, and there were no glands to pack. The flap valve shown in Fig. 28, Plate 31, was the valve he had begun with; and having begun with it and found it quite satisfactory, he naturally preferred to keep it, as it had a clear opening; as soon as ever the exhaust began from the high-pressure cylinder, it opened the valve and kept it open.

As to the curious anomaly in Table 11, enquired about by Mr. Mair (page 129)—that a rather smaller quantity of water was evaporated per lb. of coal in the compound engine, notwithstanding that the total evaporation was much smaller than in the ordinary engine—he thought this result was not anything to be particularly noted, because the evaporation, whether in non-compound or compound engines, would be found to be very varying in amount; and in another instance the opposite result was just as likely to occur.

As to the first cost of arranging an engine on the compound principle (page 127), in the two-cylinder compound engines such as he was using, with inside cylinders, Plate 30, there was practically very little additional cost as compared with the ordinary engines. Although the low-pressure cylinder was so much larger than the other, the actual difference in the cost of workmanship due to its enlarged size was very little; there was of course some additional weight. There was the additional cost of the intercepting valve, which was practically little. There was also a little additional cost for the enlarged connecting steam-pipe from the high-pressure to the low-pressure cylinder; but there was one steam-pipe less on the low-pressure side, where outside cylinders were used. Beyond these he thought there was not any additional cost whatever in the construction of the compound engine.

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The consumption of about 26 lbs. of Welsh coal per mile, mentioned by Mr. McDonnell (page 128) as that of the 17-inch cylinder engines taking the fast mail trains on the Great Southern and Western Railway of Ireland, was certainly a very satisfactory result as the average consumption for taking such a train, and he wished it could always be attained in daily practice. The use of Welsh coal was no doubt a very favourable circumstance, as on the North Eastern Railway he had to use coal of a very different nature. In this connection he might draw attention to Table 5, in which was given the consumption of coal in twenty goods engines that he had made some time ago from one set of drawings, ten of them being compound and ten non-compound. All of them were tender engines, working the heavy express goods trains between Newcastle and Leeds; they had six wheels coupled of 5 feet diameter, and their weight was approximately 40 tons. The ten non-compound engines had 18-inch cylinders and 24 inches stroke; and in the ten compounds the same size was kept for the high-pressure cylinder, namely 18 inches diameter, while the low-pressure was 26 inches diameter; the heating surface and everything else was the same in both. The working of the engines for twelve months was given in Table 5; and the actual saving of coal was 14½ per cent. in the ten compounds, as compared with the ten non-compound engines doing the same work.

The PRESIDENT enquired what difference there was in the pressure of steam in the two sets of engines.

Mr. WORSDELL replied that the non-compound engines were working at 140 lbs. pressure, and the compounds at 160 lbs., being 20 lbs. higher pressure. These engines had now been working for about two years, and not one of them had been in the shop for repairs. As already mentioned (page 134) the first had been out for about three years, without having once been in the shop for repairs, although it had done the same work daily. He had also built a number of tank engines on the compound principle for working the heavy mineral traffic from Darlington to

Tebay and Cockermouth. That line was rather awkwardly situated for water supply; but no trouble had been experienced in taking with these engines the same trains that were taken by the ordinary tender engines. In one place there was a gradient about ten miles long of 1 in 59, which of course occasioned a great strain on the engine going up it, especially if the engine had to stop for water upon the incline. It had been said that it was difficult to start with a compound engine up an incline; but he had himself experienced no greater difficulty in starting up an incline with the two-cylinder compound engine than with the ordinary engine: in fact, under certain circumstances, the compound could start much more easily.

As to the wear and tear of the boiler in compound engines, it had been feared that the boiler must suffer in consequence of the increased pressure. He had no doubt that high pressure, of which he was an advocate, especially for compound engines, was an advantage for economy either in compound or non-compound engines, if the consequent greater strains could be accommodated. There was no greater wear and tear upon the boiler in a compound engine than in a non-compound. The friction through the tubes, due to the violent draught which was induced by the rapid exhaust from the non-compound engine, was certainly greater than that attending the milder and slower exhaust from the compound engine. His own three years' experience however he thought was hardly enough to settle the question; Mr. Webb's experience dated longer than his own, and Mr. v. Borries' perhaps a little longer still, at any rate with a few engines. But it was evident that the wear and tear upon the boiler must necessarily be less, if the friction due to the gases passing from the fire-box was less. The best method of measuring the wear of the boiler, he thought, would be to take the quantity of water evaporated during a given time. Hitherto he had been rather inclined to take the consumption of fuel during a given time; because, although one might generally be dependent upon the other, it appeared to him that under certain circumstances this might not be so. The evaporation of water depended largely upon whether priming took place, owing either to an unsuitable position of the steam pipe or to some other cause; and he had heard a fear expressed that, owing to

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the lighter draught and the smaller number of the pulsations of the exhaust in the compound engine, there might be a chance of the drain upon the steam chamber of the boiler causing a disturbance to the water, and so producing priming. Such an effect however had not been found to result, and he had had no trouble in that respect in any of the compound engines. Their boilers were full size, and it might therefore be that their steam space was large enough to prevent anything of that kind from occurring. At first sight he admitted it might appear likely to occur; but even if it did, the large low-pressure cylinder had been fitted with spring safety-valves, which acted as blow-off cocks, so that if any water did get carried over into the cylinder there would be no trouble in getting rid of it. Those valves had not been put there for that purpose, but were set to a certain pressure, so that the driver should not be able to admit steam of the full boiler pressure. The pressure to which they were limited was 80 lbs. to 100 lbs., this being more than sufficient for everything that was wanted in the low-pressure cylinder.

In regard to the balancing of the two-cylinder compound engine, he remembered being warned that it would be a lop-sided engine, and that the work would be very uneven on the two sides. Practically however the work was even, because the mean effective pressures in the two cylinders were inversely proportioned to their areas; and he had in this way obtained nearly 1,000 horse-power, of which 500 was got from each cylinder as a maximum.

Respecting the consumption of fuel, during two weeks' running of the accelerated Scotch express in August last, with the same weight of train every day, one of these two-cylinder compounds, No. 1324, was tried against a non-compound of exactly the same size, with 18-inch cylinders, but having rather larger wheels; the latter, No. 1475, consumed an average of 31·4 lbs. of coal per mile, while the compound burned 25 lbs. per mile, showing a saving of 6·4 lbs. per mile, or 20·3 per cent. On the average he did not claim more than 15 per cent.; but in those two weeks' running with the same train daily there had been this saving of 20·3 per cent.

In reply to the enquiry about the spark arrester (page 119), no doubt it did interfere with the blast; and he thought one advantage

in favour of the compound engine was that it could do without the spark arrester, for the simple reason that the blast was softer. There was no harsh draught upon the fire, and consequently large cinders were not ejected.

Mr. David Joy was inclined to conclude from what had been said upon this subject that the saving of fuel in compound locomotives was mainly due to the raising of the steam pressure, while at the same time it seemed that the higher pressure could not be conveniently used without compounding. The questions of repairs, and of wear and tear from higher pressures in the boilers, had already been fought out most satisfactorily in the marine engine. Considering what had been done in the marine engine, he was confident the same might be done in the locomotive. The boilers he believed would not suffer a bit more with the higher pressures up to 200 lbs., which were likely to be reached shortly, than did the present boilers with 120 lbs. or 140 lbs. pressure. Marine boilers now working from 150 lbs. to 170 lbs. and even 180 lbs. pressure were not giving more trouble than did the old boilers at 90 lbs. The question of repairs to the machinery also he was satisfied would tell in the long run in favour of compounding for locomotives. Probably there had not yet been time to decide this point, at least so said practical men; but he was of opinion that repairs would tell much more in favour of compounding than even the advocates of compounding believed. The representation made by Mr. Worsdell was manifestly the correct one, that in the compound engine the strains were less upon all the parts, and therefore there must be less wear. This was so far the case with a large marine engine that, if it were not for compounding, it would not be possible to use the present higher pressures at all; the strain upon the large pistons at the high speed would be so enormous that no material would be able to stand it; and although in the locomotive, owing to its smaller size, the effect was not quite so palpable, it was nevertheless there, and must be taken into consideration. As Mr. Worsdell had pointed out (page 133), in a non-compound engine with 170 lbs. as the initial pressure, the whole of this was pressure producing wearing strains;

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whereas in the compound with the same initial pressure there was a cushion of 50 lbs. in front of the piston, so that the resulting pressure producing wearing strains was only 120 lbs. Therefore, instead of falling back upon the non-compound engines, there was a great future he believed for the compounds; the only question was how to work them to the greatest advantage.

In connection with the economy effected by compounding, he had heard it said that most of the compound locomotives in this country were fitted with the Joy valve-gear, rather implying thereby that this circumstance might influence the results. This however could not be the case either way. The compound system did not depend on details of this kind, but stood on its own merits, which were quite sufficiently palpable. But as a small addition to the very complete illustration of the compound locomotive and its details which was given in the paper, he submitted the following particulars of the cut-off by the Joy gear, as employed on compound locomotives in this country, which would compare with the figures furnished in the author's Tables 14 to 16 of the cut-off by the link gear and the Walschaert gear as used mostly abroad:—

Cut-off in percentage of stroke in forward running with Joy valve-gear in Compound Locomotives on the Great Eastern Railway.

Front end of cyl., per cent.	71·0	66·5	60·5	50·0	42·0	33·0	24·0	6·5
Back „ „ „	72·5	66·5	60·5	50·0	41·0	33·0	24·0	7·0

Lead 3-16ths inch constant.

Mr. J. Macfarlane Gray mentioned that in the examinations which he conducted he sometimes found marine engineers who fancied the compound engine was a contrivance by means of which the steam could be made to do work twice over; and he had met that delusion by the enquiry whether a cow when chewing the cud was enjoying a second meal, and had explained that the process was similar in the compound engine. By way of another illustration, he had also pointed out that, although it was no use to take two bites at a cherry, yet it was necessary to take two bites at an apple for fear of getting lock-jaw. The attempt to use very high pressure in a single cylinder was like trying to take the apple at one bite, and the

enormous pressures upon the bearings were then found to be impracticable; the compound engine was a contrivance for enabling the higher pressure to be used without increasing the stresses in the engine.

There was no statement in the paper of any defined relation between the boiler pressure and the mean effective pressure, when the latter was calculated by referring the whole of the power to the low-pressure cylinder. That was a very useful relation for engineers to be familiar with. If it were wished to get a certain power from a compound engine having a low-pressure cylinder of given diameter, what boiler pressure must be employed for that purpose? For marine engines there was a simple relation which he had put into the following form for the convenience of engineers:—whatever might be the requisite mean effective pressure on the supposition that the whole of the work had to be done in the low-pressure cylinder, this mean effective pressure when squared and divided by six would be the required boiler pressure above the atmosphere. This rule was altogether empirical; and if it were applied to any compound engine that was working well, he believed it would be found to hold good.

Mr. LAPAGE said that no doubt economy would be procured (page 118) by increasing the pressure in ordinary engines; but it was found, as pointed out in the paper, that higher pressure could be better utilised in a compound engine, and therefore it was used when practicable; and whatever pressure an ordinary engine could be worked at, a still higher pressure might be used to advantage in a compound, owing to the more favourable cut-off and expansion. He did not attach much importance to the pressure; but it was requisite to arrange the compound cylinders for the required capacity.

With regard to the question about the spark-arrester (page 1[illegible]), in designing the engine described in the paper the smoke-box had been made large and fitted with a wire spark-arrester of considerable area, as the engine was intended for burning wood; the sparks dropped into an ash shoot at the bottom of the smoke-box, shown in Figs. 1 and 3, Plates 23 and 24, and were periodically discharged. He had had experience with the long smoke-boxes, which answered very

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well; nevertheless the smoke-box shown in Plates 23 to 25 was large enough, and for an English-built engine he thought such a smoke-box was preferable to the extended one. The wire spark-arrester was fitted in the smoke-box at about the level of the exhaust nozzle, and interfered very little with the good working of the blast. For coal-burning engines it was not found necessary to use a spark-arrester if the engine was compounded.

With regard to the receiver, it should be remembered that the engine illustrated had been designed in 1886. Certainly the receiver was smaller than now used; and $1\frac{1}{2}$ times the size of the high-pressure cylinder was considered about the proper size at the present time. It was better to have a larger receiver, because then the low-pressure cylinder got the steam required.

As to leakage through the intercepting valve (page 132), the whole valve could be taken to pieces and looked at by the driver by merely removing the outside lid; if any part became worn it could easily be replaced, and glands and springs were avoided.

The PRESIDENT asked whether this could be done while under steam.

Mr. LAPAGE replied that it could be done while the engine was standing under steam. The valve would run he expected for three or four years without any trouble. Even if it did leak, the leakage would be very little, and would not do any harm. By starting with both cylinders by means of an intercepting valve the two-cylinder compound engine was able to start under any emergency; the action of the valve was automatic, and beyond the control of the driver.

Although it was better to have a higher pressure of steam, yet by increasing the size of the cylinders a good deal of the advantage of compounding could be obtained with the existing lower pressures. Three of the compound engines mentioned in Tables 2 and 3 it would be seen were running with the same pressures and doing the same work as the ordinary engines, the cylinders in the compounds being proportioned to what they had to do. It was easy enough to increase the size of the cylinders to get any desired power. The

ports had of course been made as large as was thought possible at the time of designing the engines, and no doubt would be made still larger as more experience was gained, because, as already pointed out in the paper (page 86), in the compound engine the clearance space between valve and piston had to be filled with boiler steam in one cylinder only and not in the two, which was a point of great importance. In the passenger engine shown in Fig. 32, Plate 32, it was seen that the steam-chests were on the top of the cylinders, which he thought was rather an advantage, as the valves could be easily got at; and the ports were consequently very short. In the goods engines for the same line the valve-face on the high-pressure cylinder was being made much lower, as close to the cylinder as possible: which could not be done in the passenger engines.

The President proposed a hearty vote of thanks to Mr. Lapage for his paper, which had given rise to so excellent a discussion.

ON THE LATEST DEVELOPMENT OF ROLLER FLOUR MILLING.

BY MR. HENRY SIMON, OF MANCHESTER.

No paper has as yet been read before this Institution, drawing attention to the very extraordinary revolution which during the last ten years has been in progress in the Manufacture of Flour by the substitution of the Roller system for the ancient method of grinding by stones. In a paper presented by the writer seven years ago to the Institution of Civil Engineers (Proceedings 1882, vol. lxx, page 191), some historical and general notes on roller milling were given, which therefore need not here be repeated; and the object of the present paper is simply to give some further information about the subsequent development and improvement of Roller Flour Milling as carried out by the author.

The completeness of the revolution that has taken place is exemplified by the fact that practically in less than ten years the machinery and methods of corn milling have been radically and entirely altered, at the cost of an immense amount of capital. The millstone, dating from pre-historic times, has been almost wholly discarded; and the miller has been constrained to unlearn the old method of manufacture and take up one entirely new, based upon very different principles. The change has had the effect of replacing more or less rude mechanical appliances by machinery designed on scientific principles, and of a high class of mechanical construction and workmanship. The best kind of roller mills, as now used for the granulation of wheat and its reduction into flour, resemble in their appearance and in the accuracy of their construction the highest class of machine-tools. This radical and important improvement in the character of the machinery employed is nevertheless not nearly so

radical or important as the improvement in the mode of working, by the combination of roller mills with centrifugal dressers, purifiers, rotary scalpers, and other machinery, so as to produce the best results in a mill working automatically on the principle of gradual reduction. The principle of progress now recognised in milling is indeed the same as that followed in other industrial establishments or manufactories, such as spinning mills, weaving sheds, sugar factories, &c.;—namely, increased elaboration and more scientific treatment, combined with consistent arrangement and a proper proportion of auxiliary machines, for enabling the largest amount of work to be turned out, and of the best quality. This change has called forth an entirely new class of milling engineers, who have by experience acquired special aptitude in following out the principle of gradual reduction; and even as early as 1878 the necessity for such special milling engineers was alluded to by Professor Kick, who is recognised as the leading continental authority upon milling. A further striking difference between the present and the old style of milling flour is that, whereas formerly the intermediate products had to be repeatedly handled, they are now entirely treated without being touched by hand throughout the process. The wheat enters the mill at one end and goes through all the machines automatically until it is delivered at the other end in the shape of such different grades of flour and offals as it may be desired to produce. The number of attendants required for the milling process proper is very much reduced in comparison with former times. Automatic action in roller milling has been attained almost simultaneously in the United States and in this country. In Austria-Hungary, formerly the leading school for milling, and the country in which roller milling originated, automatic action is not yet believed in; and accordingly very large numbers of mill attendants are still required there.

It has recently been ascertained by the writer that, owing to commercial necessities or facilities, Hungarian millers are at the present time giving their whole attention to the manufacture of from 45 to 50 per cent. of the very highest class of flour for export. This flour, which owing to the excellence of the Hungarian wheat is of splendid quality, still comes into England, although in very

much smaller quantity than before the adoption of improved milling in this country. The purification and division of middlings and semolina for high-class flours is carried out in Budapest with great care; but the grinding of the remainder, whether by stones or by rolls, is not done at all so carefully as in good automatic roller-mills in this country. In consequence of the large feed put upon their stones and rolls, very much greater pressure is used than would be necessary with anything like the proper feed, and thus the flour becomes unnecessarily heated. The greatest difference however between milling in Austria and in this country is in the reduction of the tailings, siftings, and second-class products, which have been rejected during the manufacture of the highest-class flour. To finish up these different products according to anything like a proper system is not even attempted in Budapest. As a consequence, anything after the first 45 or 50 per cent. of flour from the wheat is very much worse than in this country. With very little regard to size and quality, the material is ground and dressed, and re-ground and re-dressed, thus making out of their splendid wheat only very low brands of flour, all of which however find a ready and profitable sale in their own country. The contrast therefore stands thus between the English and the Hungarian method of milling:—from the wheats used in Hungary as high a class of flour could be manufactured automatically in this country as is made at very much greater expense in Austria; whilst the last 30 per cent. of flour would be considerably improved under the best English roller system. It may therefore be stated that Hungarian milling as a whole no longer occupies the proud position it held up to a few years ago, before the roller process had reached its present development in this country. Austrian and German millers, and it is believed even some in America, still cling fondly to the use of millstones for grinding and finishing fine intermediate products, notwithstanding that it has been clearly demonstrated by the experience of the more progressive British millers that there is no process of grinding which is not better performed by a roller mill properly constructed and properly worked, having rolls of chilled iron, smooth or grooved according to their purpose. To this day there is scarcely a really

complete automatic roller-mill, the writer believes, either in Germany or in Austria.

The introduction of roller milling in this country has caused a rapid increase in the number of large mills. Those roller millers who were first in the field have not only doubled their output, but in some cases have increased it three, four, and even five times, with corresponding profit, and naturally at the expense of their less enterprising competitors. The fact is now fully established that in a well-constructed and well-managed roller mill a larger percentage of superior flour can be made out of the same wheat than by millstones, and at much less cost and with much less expenditure of power. With regard to the power consumed by the various machines used in modern flour mills under varying conditions, the writer may refer to a paper read by him before the National Association of British and Irish Millers at their London meeting in 1887, containing an account of what he believes to be the first and only complete series of trials, which were conducted under his direction at the Kirkdale Roller Mills, Liverpool, with the assistance of Mr. Michael Longridge.

The first complete roller-mill without the use of stones in England was built by the writer in 1878 for Mr. Arthur McDougall, of Manchester, and in Ireland for Messrs. E. Shackleton and Sons, of Carlow, in 1879; the first automatic roller flour mill in England in 1881 for Messrs. F. A. Frost and Sons, of Chester. The total number of complete mills, or important reconstructions of old mills, executed by the writer alone since 1878, amounts to considerably more than 200, varying in cost for machinery, exclusive of motive power, buildings, &c., from £1,000 to £40,000 for each mill. Large roller-mills can necessarily be fitted up with greater refinement, as well as with a larger number of appliances for saving labour, than small mills.

Roller Flour Mill and Granary at Rio de Janeiro.

The most recent improvements in roller milling will be best realised, the writer thinks, from a description of the machinery and arrangement of a large mill, carried out with the utmost regard to

excellence of production, which has just been erected in Brazil for the Rio de Janeiro Flour Mills and Granary Co. of London.

Site.—In an enterprise of this nature a question of primary importance is the selection of a suitable site for the mill buildings, as determined mainly by the facility with which wheat can be conveyed to it and flour be carried away. Such a site was fortunately secured on the shore of the bay of Rio de Janeiro, and within easy access of the city. The preparation and extension of the ground for the erection of the mill premises was a costly undertaking, inasmuch as the whole of the area comprised between the edge of the present wharf and the old high-water mark indicated by the irregular dotted line WW on the plan, Plate 36, had to be filled in to an average depth of 15 feet. And further, in order that the largest sea-going vessels may be able at all times to discharge their grain without the heavy constant expense of dredging, an iron jetty was constructed, projecting 125 feet from the wharf's edge.

Buildings.—As shown in the plan and transverse section, Plates 36 and 37, there are two principal blocks of buildings, of which the one nearest the bay is used for the storage of grain and flour, and is called the store; while the other contains all the machinery for the preparation of the wheat and production of flour, and is called the mill. Both are of the same dimensions, namely 234 feet long and 46 feet wide; and each has five floors of an average height of $13\frac{1}{2}$ feet. The framework of the walls, the girders, columns, roof principals, and roof covering, are of cast and wrought iron, of which there is a total weight of about 1,100 tons. The flooring is composed of two layers of $1\frac{1}{2}$ inch boarding, and the joints of the upper layer are at right angles to those of the lower, which not only prevents the passage of dust but is also found by experience to be in a measure effectual in preventing the spread of fire. The flooring is supported on wooden joists; but the whole weight and vibration of the machines are transmitted direct to the main girders by heavy pitch-pine beams, which run from end to end of the building. The walls are composed of brick; their only duty is to make the

buildings weather-proof, inasmuch as the iron stanchions of the framework take all the strains brought to bear upon the structure.

Motive Power.—The two engines are horizontal compound tandem condensing, each with cylinders of 19 and 35 inches diameter and a stroke of 48 inches, making 70 revolutions per minute, and together indicating 800 horse-power, with a guaranteed consumption of $2\frac{1}{2}$ lbs. of coal per horse-power per hour. The power of the engines is transmitted through one crank-shaft to a rope pulley 20 feet diameter, Fig. 4, Plate 39, grooved for twenty $1\frac{3}{4}$-inch ropes. Steam is supplied by four Lancashire steel boilers, Fig. 2, Plate 37, 7 feet diameter and 30 feet long, the two flues being each 2 ft. 9 ins. diameter, and fitted with nine Galloway tubes.

Storage of Grain.—The tower A at the end of the jetty, Plates 36 and 37, contains a wheat elevator capable of lifting 65 tons per hour. As shown in Plate 37, it is of the ordinary construction of grain elevators for use in connection with ships or barges; the elevating mechanism is carried at the ends of two long levers, and its lower extremity can be lowered into the hold of the wheat-laden vessel. The lifted wheat is delivered upon an endless india-rubber band F, which carries it to the wheat-cleaning house. The band itself is utilised to transmit the power necessary for lifting the grain from the ship, and like the rest of the band conveyers used throughout the buildings is provided with automatic tightening gear. On entering the wheat-cleaning house the grain passes first through a self-acting weigher; and thence through three combined rotary separators and aspirators, which consist of rotary sieves with a powerful exhaust fan, for removing all impurities both larger and smaller than the wheat. The cleaned grain returns on the lower half of the same band which brought it in, and is shot into the foot of another 65-ton elevator B, Plate 37, in the grain store, whereby it is raised and delivered upon the top band C. This band is provided with a throwing-off carriage, Figs. 9 and 10, Plate 40, which can be anchored at any position in the building's length, and delivers the wheat right or left upon the top floor of the store. To meet special requirements in the present instance, two distinct modes

of storing the grain have been provided, namely on floors and in silos. The latter plan has in certain cases several marked advantages, of which the principal are that the silos are entirely self-emptying, and have a maximum storage capacity for space occupied. The tendency at the present time is to use silos only, the construction of which is shown in Figs. 7 and 8, Plate 40. In this granary there are four floors, each 107 feet long and 46 feet wide. Under each of the three upper floors are fixed a large number of drawing-off spouts, one in the centre of each 28 square feet of floor area. The outlets of these spouts are closed by valves, all of which are self-closing, but can be opened in sets of four by wire pulls from the ground floor. They are so constructed that upon being opened they sprinkle the wheat in a spray upon the floor below, and thus permit the free circulation of air amidst the grain as it falls. Under the lowest floor are thirty-two exit spouts S, connected with the measuring machines D, Plate 37. By the use of partition boards E, Plate 36, thirty-two distinct qualities of grain can be stored; and by the aid of the measuring machines these several qualities can be drawn off in any desired proportions by means of the two conveying bands at DD, Plate 37, running lengthways of the granary. By these the mixed wheat is carried from the floor, as also from the mixers under the silos, at the rate of 10 tons per hour, to the elevator H; and thence by the band J to the wheat-cleaning house. Wheat left to lie undisturbed for any length of time in a climate like that of Rio would, as a matter of course, mildew. To obviate this possibility the two bands at DD are each large enough to carry 65 tons per hour; so that, whilst one is supplying the mill through the elevator H, wheat can be carried off by the other band from the other half of the store, and be lifted by the elevator B from the bottom to the top of the store. Thus a complete turning over and airing of the wheat is accomplished. This granary has sufficient capacity for the storage of about 5,000 tons of wheat.

Final Wheat-Cleaning Machinery.—The wheat carried from the store by the band J, Plate 37, is first run again through an automatic self-registering weighing machine, and then passes through four

cylindrical reels, which are provided with covers composed of steel wires, and with a contrivance whereby the spaces between the wires can be contracted or enlarged at will. The cylinders sort the wheat into three distinct sizes, which throughout the remainder of the cleaning process are treated separately; the treatment is the same for each size, but the sorting into separate sizes ensures better work. Each size of wheat now passes to a "dustless wheat separator," containing rapidly-vibrating riddles and fan aspirators, by which the loose dust, chaff, oats, &c., are removed. It is further passed through a second set of separators, which can be set still more exactly, so as to remove the remaining impurities of the same kind. The next machines in the process are thirty-six cockle and barley separating cylinders. Their surrounding covers are composed of zinc, and have their interior surfaces impressed with indentations of such size and form that in the cockle machines all seeds, cockle, &c., smaller than the wheat, are lifted out, whilst in the barley machines the wheat is separated from all grain longer than itself. From these cylinders it travels to three machines called "scourers" or "smutters," consisting of vertical stationary cylinders of steel with diagonal perforations. Inside of these run rapidly-revolving shafts, carrying beaters composed of iron rods; the beaters scour the grain in its passage down through the cylinder, breaking and removing smut balls, loose bran, &c., which are then drawn away through the casing by an exhaust fan. The scouring is followed by a brushing process, which is performed in three machines, each containing four pairs of horizontal circular brushes on a vertical spindle. The upper brush of each pair is stationary, but the lower revolves rapidly; so that by centrifugal action the grain passes from the centre of the machine to the circumference of the first pair of brushes, and thence by gravity to each of the lower pairs in turn. The effect of the brushes is further to remove loose bran, dust, the beard of the grain, &c., and to polish the outer surface of the grain. After going through a final automatic weighing machine, whereby the amount of loss in the cleaning process is registered, the wheat is elevated into the cleaned-wheat bins, in which it is stored in readiness for the roller milling process.

Roller Mill Machinery.—A few of the principal machines, which have played an all-important part in the realisation of the great change in the manufacture of flour by rolls instead of stones, are represented in their most recent development in Plates 41 to 44. In Fig. 11, Plate 41, is shown a roller mill with four fluted rolls, each 32 inches long and 10 inches diameter. Fig. 13, Plate 42, shows a three-high roller mill with three smooth rolls, each 32 inches long and 10 inches diameter. A double "reform" purifier for the middlings is shown in Plate 43; and a double centrifugal dressing machine in Plate 44.

Roller mills, which have replaced grinding stones, are of two kinds, and are used for two distinct purposes: namely, break mills with fluted rolls, for extracting the kernel of the wheat from the bran; and reduction mills with smooth rolls, for reducing to flour the broken kernel which constitutes the middlings and semolina. In the Rio mill, four-roller mills are used for the breaks, and three-high roller mills for the reductions; in both cases the rolls are made of the hardest chilled iron.

Four-Roller Mill.—In Fig. 11, Plate 41, is shown a transverse section and end elevation of the four-roller break mill with fluted rolls, for breaking the kernel of the wheat from the bran. The two pairs of rolls are entirely independent of each other, and if required can be used for grinding two distinct qualities of material. The course of the material through the machine is indicated by the arrows, starting from the feed hopper A and the feed roller B, which are provided with a feed regulator C adjusted by hand, and an automatic feed-plate D balanced by a spring. The top grinding roll E, which runs at a higher speed, revolves in fixed bearings, and the slow-running lower roll F in bearings carried in the adjustable levers G. For throwing the rolls apart a combined lever and eccentric H is provided, with which is connected a link arrangement shown at J, whereby a clutch on the feed roller is thrown out of gear, and thus the flow of material is stopped. The surfaces of the rolls are kept clean by scrapers K. A magnified section of the fluted surfaces of the rolls is shown in Fig. 12, enlarged to four times full size.

The balanced automatic feed-plate D is adjusted with a sufficient spring pressure to give the proper feed upon the roller mill when opened by a certain weight of feed in the hopper at the back of the plate. The action of the feed-plate keeps the quantity of feed in the hopper, and consequently the feed upon the roller mill, almost constant: if the feed increases temporarily, the balanced plate opens till the quantity in the hopper is reduced; or if the feed decreases, the plate closes until the quantity is increased to the proper amount, thus keeping practically regular the amount of feed passing over the feed roller to the grinding rolls E and F. The advantage gained by having the lower roll F adjustable is that all wear in the working parts connected with the adjustment is taken up by the weight of the roll itself; and the distance apart of the working or grinding surfaces, which is the most important point in any roller mill, can be absolutely assured by the adjusting gear. The handwheels L are for setting exactly each end of the lower roll F, so that its surface may always be truly parallel with that of the upper roll E. The boxes M contain spiral springs, which can be set to any required tension and so give the requisite grinding pressure. As seen from Fig. 11, the spring pressure is so applied as to be in no way affected by the distance at which the rolls are set apart. Power is transmitted by belt to the upper roll of each pair; and the correct differential speed of the lower roll is maintained by double helical toothed wheels running in oil-tight casings.

Three-high Roller Mill.—In Fig. 13, Plate 42, is shown a transverse vertical section of the three-high roller reducing mill with smooth rolls, for reducing the broken grain to flour. The centre roll here runs in fixed bearings, and the upper and lower rolls are carried in adjustable levers; and similar means to those in the four-roller mill are adopted for throwing the rolls apart, for adjusting independently each end of the upper and lower rolls, and for effecting these adjustments without interfering with the grinding pressure. Two distinct materials can also be treated in this machine: the feed passing between the upper and centre rolls falls thence through the spaces between the vertical tubes A into the under hopper of the

mill; while the material to be ground between the centre and lower rolls falls through the inside of the tubes. This arrangement of cross channels has the appearance of a gridiron in front elevation. The principal advantages of the three-high roller mill are that the downward grinding pressure on the centre roll is counteracted by an equal upward pressure, so that the friction due to pressure is eliminated in the bearings of the centre roll; and there are thus only four bearings under pressure, as against eight in the four-roller mill. Furthermore the three-high roller mill occupies but little floor space.

Purifier.—In Plate 43 is shown a longitudinal section of the "reform" purifier, the use of which is of vital importance in modern milling, for by its application a perfect purification of all middlings, from flour to the coarsest semolina, is possible without waste. From the feed hopper A, by means of the feed roller B, the middlings are fed upon an oscillating sieve C, which is hung from the suspension rods E and is moved rapidly to and fro by eccentrics on the shaft D. Above and close to the silk of the sieve is fixed the grid of channels F. Underneath the sieve the travelling brush G keeps the mesh of the silk clear. Exhausting fans are placed at H H, inside an endless travelling filter-cloth J. The middlings to be purified are fed in a continuous stream upon the head of the oscillating sieve, and throughout the whole length of their travel along it are subjected to the action of air currents passing upwards through the silk direct to the fans H. The intensity of the air currents is so regulated as to allow all the good pure middlings to fall through the silk mesh into the worm conveyer K; but the semi-pure middlings are lifted up by the suction of the fans, the object of the grid of channels F being so to contract and intensify the air current immediately it leaves the silk that the unsound middlings shall be lifted clear of the silk and deposited in the channels themselves, whilst all light branny particles still remaining in the air are deposited on the under surface of the filter-cloth J travelling overhead; thus the air passing into the fan and thence back to the mill is free from dust. By the oscillation of the sieve the unsound

middlings deposited in the channels F are carried into one main central trough, which delivers them at the tail end of the machine. The stive and branny particles are continuously removed from the filter-cloth by the action of a portion of the strong blast discharged from the fans H, supplemented by suitable beating apparatus in the chamber L, and are delivered thence by the worm M.

Centrifugal Dressing Machine.—In Plate 44 is shown a longitudinal section of the author's double centrifugal dressing machine. Centrifugal machines have almost entirely replaced the large and cumbersome reels which not many years ago were the only machines at the miller's disposal for separating the flour from the other products of grinding. A two-high machine is here shown, because this form is the most useful in mills of large output, not only on account of the saving in floor space, but also because the upper machine is enabled to feed the one beneath it. The material to be dressed is fed by a worm conveyer at A into the interior of the dressing cylinder C. The flour or other product dressed through the silk or wire clothing of the cylinder is collected by the worm B underneath; while material too coarse to pass through the clothing is discharged from the end of the cylinder through the spout D. The silk or wire clothing is stretched tightly upon a cylindrical framework, being laced together along its longitudinal seam, and secured by cords at its ends to encircling rings E. The cylinder carrying the silk revolves slowly, whilst inside it revolve rapidly the finger beaters F mounted on the shaft G. The construction of these beaters is such that, whilst offering but a slight resistance, they can be twisted more or less, so as to hasten or retard the travel of the material along the cylinder. Transverse partitions are frequently added underneath the cylinder, as shown at H, so as to separate two or more sizes of flour and middlings along the length of the machine.

The sample case exhibited contains small quantities of some of the intermediate and finished products, which will serve to illustrate the following short description of the actual milling process.

Milling process.—From the cleaned-wheat bins the grain is elevated to rotary graders, which sort it into three sizes. Each sort passes between fluted rolls set with great nicety so as to break every individual wheat grain as near as possible along its crease. The broken grain is next lifted into centrifugal dressers, which take out a small percentage of flour that is contaminated with the dirt released from the crease or rubbed from the surface, and has also larger particles mixed with it. The broken wheat thence passes to other roller mills, each with finer flutes, which further open out the berry and extract the kernel until the bran is clean. After each break the granulated kernel is sifted and separated from the bran by rotary scalping or sifting machines, the aim being to produce the smallest possible percentage of flour, and the largest possible percentage of groats and granular particles, technically known as middlings or semolina. This process is continued through a series of six sets of fluted roller mills, each set being followed by scalpers. The duty of the last set of rolls, which are very finely fluted, is to clean from the bran as far as possible the last adhering portions of the kernel. The main object of the gradual reduction is to separate the kernel from the bran in as large particles as possible, with a view to the greater facility thereby secured for freeing it from the bran and germinal impurities, and afterwards reducing it into flour of the highest quality, uncontaminated by the presence of particles of bran. Any flour made during the breaking process is necessarily of rather a low quality, being contaminated by admixture of bran and germ &c., which it is impossible afterwards to separate from it entirely. In recent mills the writer has succeeded in reducing the proportion of this break-flour to as little as 5 per cent. of the total flour produced. So excellent a result has been attained by improvement in the system of gradual reduction by fluted rolls, and by separation of the breaks by rotary scalpers, the action of which is peculiarly adapted to such work. The extracted kernel or break-meal varies very much in value according to the break from which it comes. In the Rio mill it is divided into four distinct qualities, each of which is conveyed to reels and rotary graders, which dress out the break-flour, and sort the middlings, or particles nearest in size to

flour, into as many as about eight distinct sizes; and also into the same number of sizes the semolina or larger portions of the kernel, which are somewhat like rough sand. Each size of middlings goes into a purifier of the kind shown in Plate 43, to be freed from fluff and all branny portions before further rolling. Each size of semolina is conveyed to one of the semolina or gravity purifiers, in which, whilst falling in a thin stream over zigzag louvre boards, it is subjected to a blast of air, whereby the lighter portion or stive is blown away. The heavier pure semolina falls separately upon an oscillating sieve, by which it is further subdivided into four sizes. Each of these again passes down zigzag louvre boards, while a current of air drawn across the running material by a fan separates it into semolina of first and second quality, the small bran and light stive being drawn away through the fan. The germ, being of equal specific gravity with the best middlings and semolina, is still contained in them. These therefore are all now conveyed, according to their size and quality, to separate smooth-roller mills, which are so set that they reduce the semolina and middlings, but only flatten the germ; consequently the latter is readily and automatically separated in the dressing or separating process that follows each rolling. The extraction of the germ is desirable, because the presence of this oily body spoils the flour if stored for a long period, and also adversely affects its taste. No flour will stand a long journey by sea if the germ is not extracted; and the separated germ fetches a good price for cattle food. The gradual reduction is continued even in the treatment of the semolina and middlings, partly because the flour produced by high grinding or gradual reduction is better in colour and in baking quality than that produced by low grinding or rapid reduction; and partly because, the more gradual is the reduction into flour, the greater is the facility for again separating and removing further particles of bran, germ, and other foreign matter, which are still present amongst the particles of kernel, however careful may have been the purification. It is in the elaboration of the best means of effecting this object by automatic appliances that the modern improvement in roller milling mainly consists. After each careful reduction of the purified semolina by smooth chilled-iron

rolls, the rolled product is passed into centrifugal dressing machinery with silk coverings, through which the flour and reduced middlings are dressed and separated out. The flour goes to the flour packing machinery; but the middlings and tailings from the dressing machines are first separated and purified by dusting reels and purifiers, and are then further reduced by rollers, and re-dressed and re-purified, until the separation of the flour from the offals is completed. In the Rio mill this reduction by smooth rolls, apart from the granulation by fluted rolls, entails operations which while perfectly automatic are also perfectly under control.

The flour from each of the dressing machines is delivered at will into any one of the four main flour-conveyers, which run from end to end of the mill. This arrangement enables the miller to combine the different kinds of flour into any number of qualities desired. Four distinct qualities of offal are also collected. From the mill the flour and offal are separately conveyed across the yard by bands marked L in Plates 36 and 38 to the flour store, where they are all taken off and packed into barrels or sacks by mechanical packers. The last part of the process only, namely the weighing of the flour and its storage and distribution, is performed by manual labour; up to this point every portion of the work described, from the unloading of the wheat from the vessel to the packing of the flour, is done altogether automatically. The flour store has a capacity of 30,000 sacks of flour, and besides the packing and weighing machinery contains three double friction-hoists, for raising the flour for storage in the upper floors, and for loading it into the carts.

Dust Collector.—For the purpose of collecting the dust with which the air in flour mills is laden, a contrivance has recently been invented in the United States, which is applicable also to any manufactures where it is desired to free the air from dust or fluff, with a view either to the comfort of the workpeople or to the prevention of waste. The field for its application is thus an extensive one, and will become all the more so when its simplicity and advantages are more generally known.

The machine, which is called the "cyclone" dust collector, consists mainly of a plain inverted conical chamber of sheet-iron D,

Figs. 5 and 6, Plate 39. The dust-laden air, collected as usual by an exhaust fan and propelled through a wind trunk, enters the dust collector through the inlet spout A, and being forced against the surface of the cone, is made to revolve in a spiral direction downwards, as shown by the arrows. By the action of the air current and by centrifugal force, the particles of dust keep close to the conical surface, and are swept round and round, gradually reaching the opening B at the bottom, where they pass out, and are collected into any desired receptacle. The volume of purified air, on the other hand, finding itself confined as it works down the cone, turns upward in the centre and escapes through the central tube C at the top of the apparatus. The process is so simple and effective, that without actually seeing the machine at work it is difficult to credit the result, and still more to realise the complete manner in which in most cases the separation of the dust from the air is accomplished.

From the drawing and the model exhibited it will be seen that the machine has no moving parts, requires in itself no driving power, and is practically free from wear and tear. It also does away with the great objection to all previous dust collectors which strain the air through cloths or flannels, namely that the latter obstruct the free passage of the air, and gradually, but inevitably, in spite of care and cleaning devices, become filled up with soft adhesive dust, which with the moisture of the atmosphere forms a paste, and renders the filter cloth useless after periods varying from a few weeks to a few months according to circumstances. This objection is all the more serious in flour milling, because by the gradually increasing resistance offered to the air-current other machines depending upon the regularity of the exhaust are affected in the quality of their work and otherwise. The cyclone dust collector has the great advantage that it works without impairing the constant wind-pressure. It has already been most extensively applied to many industries in the United States, and for flour milling and wood working alone over 3,000 machines are there in use. In this country more than 300 machines have already been set to work by the writer within a period of a very few months and with very satisfactory results.

Discussion.

Mr. SIMON exhibited a case of samples of grain, flour, and by-products, taken from the successive stages of his roller milling process. Also a specimen of the dust collector, about one quarter the size of that illustrated in Plate 39, of the kind used for collecting shavings and small chips of wood &c. from joiners' shops; it has a spiral rib or projecting ledge winding down the inside of the cone, which is found necessary for guiding these bulkier substances down to the discharging hole at bottom, and separating them from the air escaping upwards through the central aperture at top. The one shown in Plate 39 is that used in flour mills, and is for collecting dust: for which purpose no spiral rib inside is found to be necessary.

Mr. JOSEPH FOGERTY said that some thirty-five years ago he had paid a good deal of attention to milling, having then been engaged with his father in building a number of mills in Ireland. At that time he believed there was not any roller mill in existence in Great Britain. Attempts had been made to employ rollers for the purpose of breaking the grain before it entered the millstones, but the rollers had not been fluted as they now were; the rollers had been first grooved longitudinally and then cut with transverse grooves, so that a series of minute diamond points were formed on the surface. Those rollers had done well, and possibly some of them were still at work in flour mills at Limerick. Subsequently he went to Hungary to examine the roller mills erected at Budapest; but it was then very difficult to induce the owners of the mills to allow any part of the process to be investigated by an English engineer, and they were particular not to divulge the secrets of their trade. Shortly afterwards however Mr. Buchholz, who he thought might be called the inventor of the roller process of grinding, published a work in which the attention of English millers was drawn to the subject of manufacturing a much better quality of flour than had previously been produced in this country. In the discussion of the author's former paper seven years ago at the

Institution of Civil Engineers (1882, vol. lxx, page 246) he had expressed the opinion that the days of millstone grinding were numbered; while on the other hand one of the largest bakers in London, Mr. Nevill, had stated (page 248) that he at all times gave preference to stone-ground flour. In a short time however he believed it would be difficult to get any other than roller-ground flour. The main objection alleged to the latter had been that it produced so much of what was called split flour; but by improvements recently introduced this objection he thought would be totally done away with.

It was undesirable in a flour mill to have the screen rooms attached to the milling part of the building. For it was a well known fact that flour mills were destroyed not only by actual fire produced from friction, but also by explosion, when in certain states of the atmosphere fine dust was infiltrated through the air and it became explosive. Some mills had been totally destroyed by explosion, without any one being able to say how the accident had been brought about. His father had been surveyor to several fire insurance companies, a large part of whose business consisted of insuring flour mills in Ireland; and there had generally been two or three catastrophes annually, arising from fire or explosion in the screen rooms of the mills.

Mr. Arthur Paget, Vice-President, enquired whether in referring to explosion, Mr. Fogerty meant merely to convey the fact that in a flour mill, as in some parts of a cotton mill and as in many other manufactories under special circumstances, the air was in some positions so heavily laden with dust as to be in a state to conduct flame; or whether he meant that cases had occurred of spontaneous combustion and consequent explosion. When a candle was taken into a flour mill where there was much dust in the air, it was well known that the flame would run along it; and this might be called explosion. But if it was meant that the atmosphere in the flour mill was sometimes in a state to produce spontaneous combustion, that was a novelty to himself, in regard to which he thought there must be some error.

Mr. Fogerty replied that, having acted for a number of years with his father in Ireland as surveyor to fire insurance companies, he had had during that time a good deal of experience both of fires and also of explosions in flour mills, arising from the accumulated dust in the atmosphere. Whether the explosions were caused by chemical conditions, just as hydrogen was exploded when mixed with a certain proportion of atmospheric air, he was not prepared to say. He only knew that explosions of a mysterious character had occurred and did constantly occur in the screen rooms of flour mills at times when the air became charged with extremely fine dust. It was probable that fire was communicated to the mixture by a spark from some part of the machinery or from candles; but it had also occurred that when lightning had struck flour mills there had been explosions in the screen rooms, the line of the explosion being distinctly marked at a certain height from the floor all round the building.

Attention had been drawn in the paper (page 149) to the fact of the milling process having now been rendered entirely automatic; but he could hardly remember during the last twenty or thirty years any new flour mills erected in Ireland that were not automatic. In many of them with which he had been connected scarcely a single workman could be found in any of the upper storeys; there might be one or two boys running about, oiling the bearings and looking after the driving bands; but from the moment the grain entered the elevators until it emerged in flour fit to slide into the bakers' sacks no hand touched it during the whole process. That was even under the old method, in which reels with silk on them, called dressing machines, similar to the machines illustrated in the drawings, were the sole means of dressing flour; they were very good machines, and there was not much improvement he thought in the dressing of flour in the modern quicker machines known as centrifugal machines, over the old slow-revolving silk machinery. There was however an advantage in the centrifugal machines, inasmuch as they did not take up one-sixth part of the floor space occupied by the old machines, which was an important consideration.

Vertical bins for the storage of corn ought not properly to be called silos, which was the designation given to large compartments

for storing grass and other agricultural products on the ground or beneath the ground. In the construction of these bins, which had been largely introduced in the granaries of America, it should be borne in mind that towards the bottom there was an increasing lateral pressure, caused by the height of the column of grain accumulated in the vertical bin, and that it was consequently necessary to tie the walls strongly together. A warehouse of this class, erected by Messrs. Bannatyne in the docks at Limerick, had burst asunder almost immediately after it had been filled, discharging the grain into the docks; and similar accidents had happened at Liverpool and elsewhere.

The PRESIDENT enquired whether it was owing to the bins not being strengthened by ties that the walls had burst.

Mr. FOGERTY replied that without the protection of properly constructed ties vertical bins like those shown in the drawings were apt he conceived to burst under the lateral pressure due to the vertical height of the column of grain, and to the heating and expansion of the grain if it were in the slightest degree damp. Several had burst in America.

Having visited last year some large mills in America, and also the exhibition of milling machinery at Cincinnati, he had not seen anything there at all superior to the machines described in the present paper. The three-high roller mills there used were almost identical with those illustrated in the drawings.

The superiority of Hungarian flour arose he thought from the superior class of wheat from which it was made, and from the fact that the Hungarian millers did not care to take too much out of the wheat; as stated in the paper (page 150) they were content with from 45 to 50 per cent. of superior flour out of the wheat ground. No English miller he believed would be content with so little, but would generally want to get about two-thirds of the weight in fine flour, which was an important difference. In Hungary the millers had a large market in their own country for second-class flour and middlings, which the people were not only content with, but rather

(Mr. Joseph Fogerty.)
preferred; all the superior flour was therefore sent abroad, and as yet he thought no English manufacturer could equal it in quality. Most people who were particular as to bread used Hungarian flour in their own houses, and never found that it failed to rise in the oven as the flour manufactured in this country occasionally did.

Mr. WILLIAM SCHÖNHEYDER asked whether it was necessary to have greater regularity of speed with the modern mode of producing flour by rollers than with the old mode of grinding by stones. In the old-fashioned stone mills, worked either by water or wind power, he understood almost any speed would do. In spinning mills producing the finest cottons and silks very great regularity of speed was necessary; and he should be glad to know whether this was also necessary in the modern roller mills, and what variation of speed from the normal might be permitted.

Mr. HENRY DAVEY asked whether there was any saving in the power required to drive the roller mill as compared with the old millstones.

Mr. EDWARD H. CARBUTT, Past-President, understood the objection to the old mode of grinding by millstones was that the flour was ground over and over again, after having been produced from the grain, so much so that it got heated. The benefit of roller milling, he believed, was that as soon as ever the smallest quantity of flour was made it was passed through a dressing machine and taken away, so that it did not continue to undergo rolling and re-rolling. It went through a great many more processes than it did under the stone-grinding system, and he should be glad to know how many more times it went through the machines now than formerly; he understood it went through fifteen or twenty times oftener than under the old process. In his recent visit to America he had been to see at Minneapolis the largest flour mill in the world, namely that of Messrs. Pillsbury, where 9,500,000 bushels of wheat were ground in a year, representing 7,000 barrels of flour daily, and he had been greatly pleased with the work done; fluted rollers

were being used, and there were very few men indeed in charge of the mill, everything being automatic. In that town 6,375,250 barrels of flour had been manufactured in the year 1887.

With regard to the so-called silos, he understood that each was a separate bin, and that they were not dependent one upon the other. In America they were all made of planks 10 inches wide by $1\frac{1}{2}$ inches thick, and they were put together so strongly that each was able to carry the weight of the corn put in it. He had never heard of any mill having burst its sides through expansion of the grain.

In the Armour elevator or grain store at Chicago he had been told that the grain was elevated at a speed of something like 550 lineal feet a minute to the top of the building, and was there distributed. The building was 550 feet long by 112 feet wide and 155 feet high, having a capacity of 2,250,000 bushels; it contained a 1,500 HP. engine, and three lines of rails, on each of which could be placed twelve long American cars; there were sixteen shipping and twelve receiving elevators, each having a carrying capacity of 7,000 bushels per hour; and one marine leg having a capacity of 12,000 bushels per hour, for dipping into a ship's hold. Having been much struck with so high a speed for an elevator, he wished to know whether the same thing was being done in England, as he believed was the case at the grain store at Fleetwood belonging to the Lancashire and Yorkshire Railway. In the American mill he understood the elevator had a strap 22 inches wide carrying the buckets, each of which would hold a large quantity of grain, though he did not know how much. The warehouse at Fleetwood had been fitted up by Messrs. Hick Hargreaves and Co. of Bolton, by whom he had been informed that they had constructed an experimental elevator for trying at what speed the grain could be lifted, and for ascertaining the best shape for the buckets and seeing that they properly emptied themselves in passing over the top pulley. The difficulty in an experiment of this kind was that at a high speed it became impossible to look into the buckets and see whether they were full of grain. If the elevator ran too fast, the buckets might not have time to fill themselves full, and might be carried up only part full, and might not entirely empty themselves at top. They therefore had recourse

(Mr. Edward H. Carbutt.)
to a modification of the toy called the thaumatrope; and by adapting this idea to the model grain elevator, it could be seen whether the buckets were full of grain, or exactly what quantity of grain was in them. A revolving vertical disc with four or more holes round its circumference was mounted on a centre pin alongside the belt of buckets, in such a position that the travelling line of ascending buckets was tangential to the circle described by the holes in their revolution; and when the disc was driven at the same speed as the buckets, but in the opposite direction, the buckets were seen through the holes in the disc as if they were standing still, and the quantity of grain in them could be seen quite clearly, when running at 600 feet per minute.

Mr. J. Harrison Carter, having himself had the pleasure of putting up a large mill for Messrs. Russell at Limerick, had never seen there any roller mill dating back so far as mentioned by Mr. Fogerty (page 164); but he quite agreed with him (page 166) that the old stone flour mills in Ireland of which he had spoken had nearly all been automatic. He had himself worked mills in Ireland, and so far as he knew the flour was never handled from the time the corn went into the mills until it came out into the flour store-rooms, or sometimes into the sacks, as finished flour.

With regard to the lateral pressure in the silos, he might mention that the Grain Storage Company's silos in Liverpool were built in a honeycomb shape in plan, the diameter of each being about 6 feet, while the wall between them was only a single brick thick or about 9 inches. The amount of lateral pressure in each silo had been carefully tested, and he understood that at 15 feet from the surface it was not much less than at the bottom of the silo, which was very deep.

In the present paper the automatic principle was advocated in connection with roller flour milling, and reasons were given why it offered advantages over the continental or non-automatic system. The first automatic roller flour mill in England, mentioned in page 151 as having been built by the author in 1881 for Messrs. F. A. Frost and Sons of Chester, had he believed been built by him as an automatic mill because he had been ordered by them to make it automatic; and

in that year, contrasting automatic with non-automatic systems, the author had cautioned English millers who might be intending to employ the roller process against the serious mistake of expecting that any method could be discovered which should be so entirely automatic as to require no manipulation or attention from beginning to end. Such a caution seemed to him to be somewhat at variance with the views expressed in the present paper in favour of automatic machinery.

Mr. FREDERICK COLYER having had a good deal to do with the elevation of grain, especially barley and meal, had never used a speed anything like that mentioned by Mr. Carbutt (page 169) of 550 or 600 feet per minute. Anything beyond 300 feet per minute would be thought considerable, and certainly would damage the grain; added to which, the buckets would not deliver properly.

Owing to the storage of grain in deep vertical bins, accidents had occurred in several places where the sides of the building had fallen out under the lateral pressure of the grain in the bins; and experience had proved that, unless deep bins were strongly built and well tied together as mentioned by Mr. Fogerty (page 167), such accidents would recur.

Regarding the consumption of $2\frac{1}{2}$ lbs. of coal per indicated horse-power per hour (page 153) for the engines driving the mill described in the paper, he should be glad to know what kind of coal it was, and the cost per ton, and whether that consumption was the result of an experiment or of actual working over a period of some months; also what was the cost of coal per sack of flour made. As so little was known on the subject, it would also be of interest to learn what was the relative indicated horse-power used in different parts of the milling process: in the dressing machinery per cwt. of wheat cleaned, and in the break-rolls per sack of flour produced; also in the smooth or finishing rolls. There was no statement in the paper as to the weight of finished flour turned out per hour in this mill, nor as to the speed of the rolls of 10 inches diameter; the circumferential speed he believed was generally about 350 feet per minute. What was the maximum speed at which the rolls were

(Mr. Frederick Colyer.)
driven? and had it been found in practice, if the speed was much increased, that damage was done to the flour? The average weight of wheat ground per indicated horse-power per hour he should also like to know, as well as the difference in this respect between stone mills and roller mills; and the percentage of best flour made from the wheat ground. Had rollers with steel jackets been used, and with what results?

Mr. Charles Neate as an old resident in Rio had acted as consulting engineer for the flour mills described in the paper, which had been designed by the author and carried out by Messrs. De Morgan Snell and Co. at a cost of upwards of £200,000. A great deal of work had had to be done which was independent of the absolute milling machinery. There had been two acres of ground to reclaim, and two large buildings to erect upon it, a quay 500 feet long to construct, a pier to make, a chimney to build, and so on: altogether therefore the sum spent in equipping the ground and the mills generally had been large relatively to that spent upon the milling machinery proper, which latter amounted to about £50,000. With regard to the machinery, which had been designed by the author, he had himself had the simple duty of ascertaining whether the machines themselves were good for their kind of work, and he was glad to say he considered them the best of their kind; better machinery he thought could hardly have been sent out. The mill had now been set to work, and in a short time he hoped would give practical evidence of the excellence of the machinery. With regard to risk of fire, the buildings were almost entirely of iron, with the exception of the floors and joists and the spouting for the grain and flour, all of which of course were of wood. The building would be lighted by incandescent electric lamps; and ample means had been provided for extinguishing fire by the use of a thousand Grinnell sprinklers with a high pressure of water, which were distributed over the whole place; and there was also a Merryweather fire-engine in a building apart from the granary. The fine dust of flour, he was aware, was exceedingly inflammable, and bad accidents had occurred in consequence of its explosive nature; but every possible

precaution had been taken that could be thought of, and he hoped therefore there was not much risk of fire.

Mr. WALTER H. THELWALL, representing Messrs. De Morgan Snell and Co., mentioned that there had been considerable difficulty with regard to the foundations of the granary at Rio, in consequence of their having had to be carried down to a great depth in land which had been only temporarily reclaimed from the sea before the quay wall was built. The quay wall had now been constructed, and it formed a permanent reclamation for all that area of land. The building being constructed of a framework of cast and wrought iron, as described in the paper, had the advantage that the framework of iron was put up without any scaffolding, and the brickwork was then built over the ironwork erected in advance. The tower at the end of the pier was constructed of wrought iron; and the pier itself was built of 6-inch steel piles let into holes in the rock, the superstructure being of wrought iron. The whole mill was fitted up with electric-light apparatus supplying about 600 lights; the dynamos were made by Messrs. Mather and Platt, and the engines by Messrs. Richard Garrett and Sons.

The silos shown in the drawings had not been constructed; but all the floors had been divided into bins by wooden partitions carried up almost to the ceiling of each floor, as shown at EE in Fig. 1, so as practically to have both the floor system and the silo system combined. With regard to the lateral pressure of the wheat, some experiments carefully carried out in Liverpool by Mr. Roberts a few years ago had led to the conclusion that the pressure of the wheat upon the sides of the bins in no case exceeded 50 lbs. per square foot when the wheat was in good condition; but of course if it began to swell the pressure would become much greater.

The PRESIDENT asked what was the diameter and height of the bins in the experiments referred to.

Mr. THELWALL replied that according to the experiments the diameter affected only the pressure upon the bottom of the bin.

(Mr. Walter H. Thelwall.)

Mr. Roberts he believed had experimented up to a height of about 50 or 60 feet with silos 1, 2, and 3 feet square, and had found that the pressure upon the bottom varied with the diameter of the bin, but was in no case more than a small fraction of what the total pressure upon the bottom would be if the wheat acted like water. In those cases in which the bins had burst he should imagine that the wheat must have got into a bad condition, in which it ought not to have been stored in bins at all.

Mr. PERRY F. NURSEY had seen the cyclone dust collector at work very successfully six or eight months ago at Messrs. A. Ransome and Co.'s works at Chelsea. In one of the machine rooms there was placed over each of the machines a hood, which was connected to a horizontal pipe 6 or 7 inches diameter, running along near the ceiling of the room for a length of 60 or 70 feet to a fan at the end, which was driven at a pretty fair speed; and the pipe was continued from the fan out across the yard to the dust collector, which was placed near the boiler house. The waste products of the wood-working machinery consisted of sawdust, shavings, and large chips of 2 or 3 inches cube, all of which were rattled along rapidly through the pipes and through the fan into the dust collector, whirled round therein, and quietly deposited below. It was a remarkable contrivance, and it seemed at first perhaps a little incomprehensible how a current of air carrying all that dust with it should be made to issue pure and clear from all atoms and particles through the central orifice in the top of the collector; nevertheless this was actually the result, as any one putting his face over the orifice would soon find out.

Mr. JAMES ARMER said the cyclone dust collector had within the last two years been successfully used for extracting moisture from compressed air. The fog which naturally collected in compressed air was almost instantaneously extracted by this means, and much more efficiently than by leaving the air standing for a period of five or ten minutes. The appliance through which the compressed air was passed was almost identical with the dust collector described in the paper, the only difference being that the base instead of being

conical was cylindrical; the moisture was drawn off from the flat bottom by means of an automatic cock with perfect regularity, and the compressed air was discharged very much drier than it would be if it were cooled down another 10 degrees. That was a curious and satisfactory fact in connection with the manufacture of cold-air machines.

If the pressure of the grain in the bins was so small upon the base, it seemed to point to the fact that there must be a great deal of lateral pressure, not merely the same lateral pressure as the vertical pressure upon the base of the bin, but also that due to a wedging action against the sides of the bin; otherwise the pressure upon the base would be equal to the actual weight of the entire vertical column of grain. Many of the Members would doubtless remember seeing at last summer's meeting in Dublin the bins at Messrs. Guinness's brewery, and would have noticed how solidly they were constructed, and wisely so, for withstanding the lateral pressure.

Mr. Seth Taylor, of Waterloo Flour Mills, London, was glad to express the obligation of his craft of British millers, and of roller millers generally, to the author and all other milling engineers, for the great service rendered to millers in enabling them to hold their own with foreign competition, which otherwise might have driven them out of the field. Up to a few years ago they had all been naturally wedded to millstones. Some few experiments had been made in roller milling in a crude way, but none had been successful. The system of Mr. Buchholz, introduced nearly twenty years ago (Proceedings 1872, page 225), was so elaborate, complex, and difficult in working, that it had been a failure; still it had been the germ of the present roller milling. There had also been at that time Carr's disintegrator (Proceedings 1872, page 28), which it was then thought was going to produce a great revolution; but that too had been tried and found wanting. In the disintegrator the wheat was shattered to pieces by concussion, and the semolina produced by that process was afterwards reduced by rollers. The object in that case had been to make as much flour as possible by the concussion; but the millers at that time did not know

(Mr. Seth Taylor.)

that the best of the flour was contained in the harder portion of the wheat, which was the semolina. His own mill in London had been constructed for him by Mr. Simon, and from the experience of his system he had learned most that he knew about roller milling; and as far as he knew it, this system as carried out by him was as good as any extant. In reality the general principles of all roller mills were identical; they differed only in the mode in which they were carried out according to the owner's ideas. They consisted in breaking the wheat by degrees, so as to produce as little flour as possible by each operation, in order that the flour might ultimately be produced by the smooth rolls from the granular portions of the grain after these had been separated in the purest condition.

As to a difference in power with millstones and rollers, according to his own experience the power was about equal. It might be stated by those interested in roller milling that the power was less with rollers; and this might no doubt be so in comparison with ill-fitted stone mills that were not worked up to their full capacity. Many stone mills had largely increased their output with the same power by the introduction of roller milling, but those had been mills which had been imperfectly fitted and had not previously been worked up to their full capacity. From his own experience of three different mills, he could state that his production had not been increased by roller mills which were driven by the same engines that had before been worked at the same power for stone milling. Where the production had been increased by rollers, it was because the same mills had been ill-fitted and ill-developed under the old conditions. The actual horse-power required for the production of flour by either plan of grinding differed according to the nature of the wheat. Some wheats took twice as much power to reduce as other softer kinds. Mills which were run merely with soft wheats would be pulled up by harder wheat. There was no absolute definite rule: it was simply a question of all-round calculation, and taking it roughly the power was about one horse-power per hour per bushel of soft wheats up to two horse-power for hard wheats. The great advantage of rollers as compared with millstones was that there was less of the outer cuticle of the wheat mixed with the flour in roller

milling. The action of millstones was accompanied with a certain amount of friction, whereby the outside of the wheat was reduced to an impalpable dust, which when once mixed with the flour could by no possible means be separated from it. By the roller system the wheat was torn asunder; the particles were separated in larger pieces; and by the gradual nature of the process—the flour being sifted out at each operation and the particles of bran being extracted by means of the exhaust—at each stage a purer flour was obtained, namely a flour which contained the proper food for man, separated from that which was the proper food for beasts.

The automatic principle was not new as applied to roller mills; stone mills also were automatic, where properly fitted. In his own stone mills there was no more handling of the material than in his roller mills. That the mills of both kinds should be automatic was of great importance in saving labour and in regularity of work. No man could work with the same regularity as an automatic machine; and there was consequently a great advantage in the automatic system as compared with hand labour. When he saw the Hungarian mills many years ago, he had been surprised at the number of men, women, and children, running about with sieves and utensils of different kinds to carry the wheat and products from one part of the mill to another. That was now entirely avoided in the present elaborate system of separation, each product being taken in its own particular conveyor, and conveyed automatically to its proper destination.

The PRESIDENT asked what was the present number of separations.

Mr. TAYLOR replied they were so numerous that it was almost impossible to count them. One miller would make more separations than another, and the products were separated in rather different ways; but the general principle was the same in all the present plans of roller milling.

As to the disadvantage of the wheat being ground over and over again by millstones, no doubt that was so to some extent, though

(Mr. Seth Taylor.)

with properly adjusted millstones it happened to a less extent. The eye of the millstone should be hollow; and only at their circumference should the stones be close together; but even with the best adjusted millstones the flour would still get operated upon oftener that it should be. In roller mills, the rollers working horizontally, their point of contact was of course only on their centre line; so that directly the material had been dealt with at that point it was released at once, and was not further treated until it came to the next operation, where it had to be reduced to a still further fineness. In the present mode of conducting the process of gradual reduction the number of times the material would go through the successive fluted and smooth rollers might roughly be twenty times.

The PRESIDENT asked whether it was a fact that the roller machinery was not rigidly automatic, but capable of adjustment.

Mr. TAYLOR replied that it was capable of adjustment in all cases; and a greater or less number of machines could be put on the wheat, according as the products might require more or less treatment.

Mr. JOHN FERGUSON, of Crescent Foundry, Cripplegate, London, wished to say a word on behalf of the old-fashioned millstones. The elaborate system described in the paper showed that along with roller milling there had been introduced a large amount of superior machinery which the millers of the old school had never thought of. Under the old system there would perhaps be one brushing machine, or perhaps in its absence all the purification of the wheat would be done by winnowing with a fan, whereby the dust would be drawn off; and then after grinding by the stones there would be one large dressing machine to perform all the rest of the operations. But now, on the other hand, there were some twenty or thirty sifting processes, for which along with the rollers had been introduced machinery of the most elaborate kind, washers, brushes, smutters, graders, semolina purifiers, centrifugal

dressing machines, and silks very superior to any ever known with the old stones. The roller mills seemed today to be getting the credit of all that had been done in the improvement of milling, whereas as a matter of fact the improvement was largely due to the introduction of this superior dressing machinery in connection with the rollers; and if the old stones received the same advantages as the rollers in the better class of dressing machinery introduced with the latter, he thought they would give better results. From the experience he had had in fitting up a roller mill for Messrs. Appleton at Stockton-on-Tees, and from what he had also seen of a good many other roller milling arrangements, he was of opinion that, if the stones got the same chance that the rollers had received in regard to the rest of the machinery, they would do much better work. It was therefore highly desirable, he considered, that the stone millers should be induced by engineers to understand that —by the adoption of better dressing machinery and better methods, and, as in one or two mills he knew in London, by the introduction of high grinding with stones and the subsequent reduction of the middlings by stones better dressed—they would be able to produce better flour by their stone mills, and would bring about a revival of their milling trade in this country, notwithstanding the present large development of roller milling.

With respect to the germ, roller millers had taken up its elimination and said this was an advantage; bakers did not. It seemed to him that in roller milling the food properties of flour had been largely sacrificed to colour, and that as a matter of fact a better or more wholesome food was not obtained from the flour when white than when it was a little dark. It had been said (page 177) that the food for beasts was taken out of the white flour, while the food for man was preserved. That might be true, but it must not be forgotten that the beast was proportionally stronger; and it was fair therefore to assume that, if the beast became strong and muscular on the portion which was eliminated, man would be better for receiving this portion also.

The introduction of roller milling into this country had been accompanied by a large quantity of foreign machinery, particularly

(Mr. John Ferguson.)

German and Hungarian, about which there had been a craze some years ago. But it had been of very inferior make, the rollers being actually fitted with white-metal bearings with a view solely to cheapness of first cost. The consequence had been that on starting the mill the white-metal ran out of the bearings. The rollers ran at high speeds, and there was a heavy pressure on their bearings; he was not sure but that on the whole the power absorbed by the heavy pressures on the roller bearings was greater than by the bearings of the old millstones. The white-metal bearings gave endless trouble until they were replaced by the hard gun-metal bearings now used, which were requisite for standing the work. The same had been the case with the milling machinery that came from America, all of which had originally been made with white-metal bearings; at the speeds at which they ran it was almost impossible to keep the bearings from melting, and then the whole machine had to be stopped.

Mr. Francis Ashby, of St. James's Steam Flour Mills, Croydon, having had experience of both systems of milling, said that, in regard to the division of the wheat grain so that some of it should be food for man and another part should go to the beast, he had found man did as a rule select the product offered from the roller mill in preference to that offered from the stone mill. The beast had the opportunity of getting the nutrition from the material to a much greater extent than man, inasmuch as a sheep's intestines were thirty times longer than its body, while those of a man were only three times the length of his body; and therefore the sheep had a longer apparatus for dealing with some of the coarser material, and more time to spare.

Explosions in flour mills were certainly very extraordinary; and he should be glad if engineers could tell the conditions under which they really took place. Although it was the fact that there was a state of the atmosphere in which, when charged with dry particles of dust, it would explode with terrific force, equal to that of gunpowder, gun-cotton, or any other well-known explosive, yet no one had ever succeeded hitherto in catching the atmosphere in

exactly that state to examine it; the explosion took place before people were on their guard. It was curious that in some mills a gas jet had even been kept burning inside the dust collector, which was usually a large receptacle or a large room, covered with sacking or gauze, where the heavier particles of dust might settle down owing to a larger space being allowed for the dust-laden air to spread out in. That was one of the most dangerous parts of the mill; but he had known some millers to keep a gas jet always burning there, and yet they had never had an explosion in consequence.

The centrifugal dressing machine was certainly a very great improvement, mainly because in the old machinery the principle of gravity alone had been used in the sifting process, whereas the new machine utilised the two powers of centrifugal force and gravity together. By running the centrifugal machine at a different speed according to the quality of the material to be dealt with, and clothing the cylinder with the right mesh, the exact separation that was required could be obtained with precision: material of heavier specific gravity was treated at a lower speed, and material of lighter specific gravity at a higher. For making good flour it was important to granulate in such a way that the particles should be assorted evenly, so that the flour sent to the baker should be even in size. In this particular there was considerable advantage in the centrifugal machine, which not only produced such a perfect separation but really did it at less cost: so that it was an immense improvement in flour mills.

In England, where labour was comparatively dear, the automatic principle was the real secret of success in roller milling. A profit could not possibly be made upon roller milling here if as much labour were expended upon it as in the southern parts of Europe. But this did not exactly prove that automatic roller milling was absolutely the most perfect way of producing flour. It was said that the best flour still came from the south of Europe. That arose partly from the selection of the wheat; but no doubt the non-automatic plan there in use afforded better opportunities for a skilful operator to make selections. In some of the Hungarian mills not

(Mr. Francis Ashby.)
only was the semolina carefully graded, but separate sorts were also selected out of it, and the miller could almost tell where a particular handful of semolina came from in the wheat berry, and could thus assort from the berry the exact particles that he wanted. That could hardly be done in an automatic mill. Another feature was that a miller was dealing with an organic substance and not with an inorganic; and there was all the difference between a berry of wheat and a piece of rock. The automatic machinery was not so contrived as to give the organic matter time to die; but the non-automatic mill could give certain portions of the wheat berries time to change and die, somewhat in the way that a nut might wither, so that the outer husk could be more easily removed. Just in that way therefore a non-automatic mill skilfully managed might be made to turn out a better quality of flour than an automatic mill. The skill which had been brought to bear by the author and other milling engineers upon the difficult and apparently impossible task of rendering profitable to English millers the almost interminably long series of processes previously carried out in the south of Europe deserved, he was sure, the highest commendation: it had indeed been a most difficult task, but step by step it had been successfully accomplished, and it was one of the marvels of the last ten years.

With regard to the power used, it was reckoned that, if a mill did not consume more than six horse-power per sack of 280 lbs. of flour turned out per hour, it was not badly worked. He did not know whether there were any millers doing that work with less power than this; but a great many were using nine horse-power per sack of flour per hour, not including the cleaning of the wheat.

It could not be too clearly borne in mind that the characteristic feature of the elaborate system of reduction carried out in connection with roller milling was the continuous separation of the finished from the unfinished products in each successive stage. The bran and a little flour and the semolinas were the products of the first set of operations, which constituted what were called the wheat breaks. Then afterwards, in an altogether distinct set of operations, constituting what was called the reduction proper, the semolina was

ultimately converted into flour of different degrees of fineness, the purifiers, centrifugal dressers, and smooth rolls being the principal appliances employed for this purpose. The great advantage gained over the old method lay in the fact that, as fast as the material was broken down step by step, at each act that which was finished was removed. Whereas in the old process bran was being ground over and over again between the millstones, simply because there was no means of eliminating from between the surfaces of the stones the portion which was already ground sufficiently, in the new process the grinding instead of being done continuously was done step by step, and at each stage just as much of the product as was finished was removed, whether it was finished flour ready to go into the sack, or finished offal wholly cleaned from any other useful product.

Mr. HENRY DAVEY gathered from the data which had been furnished in the paper (page 153) and by Mr. Ashby (page 182) that 1 lb. of coal might roughly be reckoned to produce about 20 lbs. of flour.

Mr. SETH TAYLOR said he had seen the horse-power tested, and the result altogether depended upon what drive or rate of feed was arranged for the stones or rollers, according to the nature of the wheat. The quantity of flour that could be turned out per horse-power per hour depended entirely upon the proper adaptation of the speed of grinding to the quality of the wheat.

Mr. THOMAS A. ADAMSON mentioned that in 1881 Messrs. Carmichael's mill in Belfast had been fitted up as a roller mill by Messrs. John Rowan and Sons. So far as he knew, the old method of stone milling had up to that time been used all through Ireland, and worked automatically; and the Belfast mill he believed was the first complete roller mill fitted up in Ireland. Having at that time been connected with the firm mentioned, he had made many sets of rolls for milling, together with centrifugal machines. Of the latter some had been supplied to Mr. Seth Taylor and others to Mr. Ashby.

Mr. William Stringer, representing Mr. Simon who was unfortunately prevented by ill-health from being present, said that the construction of the silos or bins was a subject to which during the last few years special attention had been given by the author, who in company with himself had travelled in the different countries of Europe, and seen most of the principal silos and the different modes of construction. That there was not a great lateral pressure had been clearly shown by Mr. Carter, who had instanced (page 170) one of the largest silos in England, in which there was only a single brick thickness of wall to resist the lateral pressure; the bins of that silo in Liverpool he understood were as much as 7 or 8 feet diameter. The lateral pressure in bins he believed was sometimes much overstated. From Mr. Roberts' experiments in Liverpool (page 173) he believed the conclusion arrived at was that after wheat had been piled up to twice the diameter of the bin it ceased to increase the lateral pressure. Necessarily the whole weight was eventually supported on the bottom; but it did not settle upon any particular part of the bottom. The wheat in the bin formed itself into a solid column; and if any part of the bottom of the column were supported, the whole weight of the column would be supported thereby, just as if the column of wheat were a solid piece of sandstone. Similarly if a hole were cut in the bottom of the bin, there was only a small amount of pressure on the part cut out: so that in actual practice a thin wooden slide, not more than $\frac{1}{2}$ or $\frac{3}{4}$ inch thick, was sufficient to close any aperture in the bottom of the bin. Having been over the grain warehouse at Limerick, referred to by Mr. Fogerty (page 167), he had never heard of its having burst asunder; a portion of the wall had given way through defective foundations, but the bins had remained intact and none of the grain had been lost or injured. The dock was some 70 yards distant or more from the present granary. The practice of tying the bins was not adopted in recent constructions. The most approved construction at the present time was that used generally in America, and at Fleetwood and other places in England, and was very simple. Lengths of timber, the longer the better, were used much in the same manner as bricks for building, being laid

horizontally in courses; and each layer was securely spiked to the one beneath it, so that when the building was completed each of the four vertical sides of all of the bins formed a wall built of wooden layers. The planks first used were about 10 inches wide; and even at Fleetwood the wall commenced with a thickness of 7 or 8 inches at the base, tapering gradually to about 4 inches at the top. But it was now found that bins 7 or 8 feet square did not require their walls to be more than 3½ inches thick when constructed of timber in this way, even though tie rods were not used at all to aid in resisting the lateral pressure. A bin so constructed he understood had recently toppled over in America, through a defect in the foundations; but the bin itself had remained intact and whole, as when built.

It seemed impossible to say with accuracy what was the amount of power required in roller milling as compared with stone milling (page 168); so much depended upon the hardness of the wheat ground, and upon the simplicity or otherwise of the process of milling by stones. The class of wheat ground by Mr. Taylor's mill (page 176) was very hard, and as a consequence it took a large amount of power; for, as in the process of roller milling a great portion of the grain was first made into semolina and then reduced to flour by smooth rolls, it followed that, the harder the wheat, the greater was the quantity of semolina produced, and the smaller was the difference in the power required in roller milling as compared with stone milling. In other districts however, where wheat of medium hardness or soft wheat was used, the power saved by the roller system was considerable, amounting to as much as fully one third. But this saving was not due to the substitution of the better class of lighter running machinery in place of ill-fitted and ill-developed machinery of older construction (page 176). For the mere turning round of all the machinery at the proper speed in an ordinary roller mill running empty absorbed as much as half of the power required to drive it when turning out the flour, and a great deal more than on the old and simpler millstone system was required for turning the machinery round when empty. After the mill had been brought up to proper speed, then the further power required for reducing flour

(Mr. William Stringer.)
from medium wheat by the roller process, as compared with that by the stones, was not much more, he thought, than one half. Hard wheat required more than twice as much power for actual grinding as medium wheat; not double the whole power put into the mill, but double the effective grinding power after all the machinery had been already brought up to speed. For the medium wheats, whether mixed or treated singly, the power required for the milling proper, as distinct from the wheat-cleaning machinery, was about 8 horse-power per sack of flour produced per hour; while including the wheat-cleaning machinery and all the shafting connected therewith, it amounted to between 9 and 10 horse-power per sack per hour. Hard wheat treated by the same machinery would take about 12 horse-power per sack of flour per hour. In a mill indicated a few days ago the power was from $8\frac{1}{2}$ to 9 horse-power per sack of flour per hour, including all the machinery. With medium wheat the power absorbed by the fluted break rollers, by the smooth rollers, and by the dressing machinery, was pretty evenly divided into thirds; the break rollers took one third, the smooth rollers another, while the remaining third was taken by the dressing machinery. But with hard wheat the smooth rollers took much more, and in some cases would absorb half the whole power. The subject of power had been very fully gone into by the author in his paper in 1887, referred to in page 151, in which the actual power taken by the various machines in the trials made had been clearly given. Having himself superintended those experiments for three months, he had taken great care to arrive at as accurate a statement as could be obtained. No result had been regarded as satisfactory to be recorded which had not stood the test of from fifty to a hundred repeated trials for its confirmation.

With regard to the now almost universal use of automatic mills in this country, in the present paper the author had chiefly had in view the distinction between the automatic system and the Hungarian and other non-automatic systems. It was the fact that in Hungary there were not any automatic mills, and therefore a great deal of manual labour was employed, and also serious disadvantages were suffered with regard to quality.

Having been twice in Budapest during the last twelve months, and visited several of the mills in that city, he had been most particularly struck with the circumstance that, after the high-class flour had been very carefully abstracted, very little attention was paid to the reduction of the remainder; all that was attempted was just to get the flour out of it as quickly and with as little trouble as possible. This had been accounted for by Mr. Fogerty (page 167) by saying that the native population required that coarse flour and preferred it to a better class. But by the non-automatic method it was literally impossible to arrive at any better result, as he had himself found to be the case in three years' working of non-automatic roller milling. For if all the by-products from each grinding were received into sacks, any one grinding would yield six or seven different by-products in as many different lots of sacks; and each of these when ground again would yield six or seven other different products, which would all have to go into different lots of sacks: so that after a few reductions there would be some thousand different sorts to be kept separate, which in anything like a large mill became utterly impracticable. As a matter of necessity therefore these products had to be mixed together; and consequently in a non-automatic mill the residue was of an inferior quality, and could not be worked up with anything approaching the completeness or success with which it was treated in automatic mills in this country. A non-automatic mill, Mr. Ashby was right in saying (page 181), gave a skilful miller scope for effecting a separation which was not attained by even the highest class of automatic mill; but this was the case only so long as the reduction had not been carried beyond two or three times, after which the by-products became so numerous that it was impossible to classify them or keep them separate. The best therefore had to be made of the whole material; and it was undoubtedly a fact that, if all the flour produced from the berry in an average automatic roller mill in this country was compared with all the flour from a similar berry in the best non-automatic mills on the continent, the flour from the automatic English mill would be worth some shillings more per sack.

(Mr. William Stringer.)

Except in a very few machines, automatic milling did not depend on any regular speed (page 168). Both the rollers and the dressing machines could vary considerably in speed, as much as 30 or 40 per cent.; but in sieve machines and purifiers and elevators there was not a margin of more than 10 or 15 per cent., and these particular machines must therefore run pretty regularly at one speed. If however they were adjusted for a particular speed, and the mill went permanently at a lower speed, they could be re-adjusted for the lower speed without any difficulty. The speed of the 10-inch break rolls was about 350 revolutions per minute, and of the smooth rolls about 180 revolutions.

In reply to the enquiry (page 171) about the coal referred to in page 153 of the paper, it was anthracite, and he had heard 30*s.* per ton mentioned as its cost, but did not know whether this was correct. The $2\frac{1}{2}$ lbs. per horse-power per hour was the consumption guaranteed by the makers of the engines as the limit not to be exceeded; it had not been tested. Much less was consumed in the Lancashire mills, as little as $1\frac{3}{4}$ lbs. per horse-power per hour.

With regard to the views expressed by the author in 1881 respecting automatic action (page 171), it must be borne in mind that roller milling was a progressive science, in which a rapid advance had been made during the last seven or eight years; and in endeavouring to keep pace with this advance the author had been following what he believed to be a right course. He had certainly found that a strictly automatic mill without power of adjustment was not desirable; and he did not advocate or adopt that principle in any of his mills. An automatic mill in the sense of doing away with labour, and yet having each machine perfectly under the control of the miller, was what the author had kept in view throughout the present paper.

The President, referring to the question of the pressure in vertical bins containing grain, pointed out that when the diameter of the bins was limited to 6 or 8 feet the pressure on the bottom depended upon the limiting angle or natural slope at which the free sides of a pile of wheat would stand without slipping; and the

pressure on the bottom of the bin was no more than that of a cone whose base was the bottom of the bin and whose sides stood at that natural slope. All the grain stored in the bin above that bottom cone had its weight supported by its lateral thrust against the sides of the bin; and the amount of the lateral thrust was determined in the usual way by a triangle of forces, in which one side was at right angles to the natural slope of the grain and the other two were vertical and horizontal, the last representing the horizontal thrust. That was the reason why the slide closing the bottom aperture of the bin was so free and easy to move, having to support only the cone of grain which really rested on the bottom, while the whole of the rest was practically supported by the sides of the bin. In wider bins of course the apex or top of the cone lost itself, and under the same principle an intermediate arrangement developed itself, in which there might be a much larger solid mass of grain resting upon the bottom of the bin. This was the way in which he had calculated the strains, when called upon to construct work of that kind. In this mode of calculation no cognizance of course was taken of any swelling of the grain, and of the bursting strains thereby occasioned, which were matters for independent consideration.

As illustrating how even a study of botany might be useful to a mechanical engineer, he had been interested in observing how the noisome germ of the grain—so useful for the growth of wheat, when it got into its proper place, the ground—could be so injurious when stored in the flour (page 161); and how beautifully it was arranged, by taking advantage of the mere flattening of the germ between the smooth rollers, that it was so easily removed afterwards in the dressing.

With regard to flour explosions, he had not heard any one venture to suggest, in response to the enquiry wisely made by Mr. Paget (page 165), that there was anything like spontaneous combustion or explosion. His own impression was that this flour dust filling the air in a chamber partook of precisely the same nature as coal dust in a coal pit, where explosions had taken place without any assignable cause except that of the flame communicated by the explosion of blasting powder, and had set the whole pit in a

(The President.)
blaze when there had not been gas to account for it. What was still sought for in flour-mill explosions was the communicating spark, which remained hitherto undiscovered. There were of course conditions of the atmosphere in which by extreme dryness the explosive character of the flour was intensified; while if damp was in the air there would be no danger of any such accident. Under a particular condition of atmosphere, a spark produced by a man walking along in the mill with his hob-nailed boots and striking a bit of flinty grit on the floor might at once cause an explosion. He had himself heard of a case where a light was taken into the flour chamber, and the whole place exploded. Although there was still wanted some definite information as to how the spark was communicated to produce these explosions, it seemed clear that a spark must be communicated in some way or other to an explosive mixture; and equally clear that the idea of the explosions being spontaneous might be dismissed.

An allusion had been made by Mr. Ferguson (page 179) to the question of the food properties being sacrificed to colour in certain modes of milling, whereby that which ought to be given to man was being given to animals. It was true that the bran or husk contained a little silicious ingredient which might prove irritating to some persons, though not so to animals; but there was another product called "sharps," which was deemed very good for pigs, which he believed would be very useful also for man and did not contain that silicious ingredient. He did think there was some truth in the allegation that too much had been sacrificed to colour in the flour produced; and it was astonishing how fashion influenced such a matter, for the industrial classes were as anxious as the wealthier to have their flour as white as it could be got.

All must feel very much obliged to the author, he was sure, for the care with which his paper had been prepared; and would join in returning a hearty vote of thanks to Mr. Simon, and also to Mr. Stringer for his reply in the author's absence.

Mr. W. S. Lockhart wrote to ask whether any of the unaccountable explosions which took place in flour mills might not be caused by

a spark of electricity from some of the revolving screens or other machinery. In other manufacturing processes, notably that of paper-making, electricity was often generated to such an extent as to necessitate special provision for taking it off; and though the conditions might not be so favourable for its generation in a flour mill, it was perhaps due to this circumstance that more explosions did not take place. To cause an explosion, four conditions would probably have to be coincident :—first, a certain electrical state of the atmosphere; second, the right condition as to speed, friction, &c., in some one of the machines; third, the existence of a convenient point for inducing the discharge and producing the spark; and fourth, an explosive state of the stive-laden air of the mill. Given these concurrent conditions, an explosion would seem inevitable; but perhaps they were not frequently found all simultaneously co-existent. Another possible cause which occurred to him was that an accidental deformity in a pane of glass might so catch the rays of the sun as to focus them, and ignite a few particles of dust floating in the air.

Mr. Simon wrote that, with regard to the adoption of automatic action in flour mills, he fully concurred in the statement that stone mills in this country had been more or less automatic for a long time before the introduction of roller milling. All that was intended to be conveyed in page 151 of the paper was simply the fact that he had not himself built any automatic roller mills earlier than the dates there given: without going into the question whether earlier automatic roller mills might have been built, with or without the use of stones also. The first complete roller mills without the use of stones in this country had been built by himself for the following millers :—Mr. Arthur McDougall, Manchester, August 1878; Messrs. Ashby Son and Allen, Croydon, and Messrs. J. A. Ingleby and Son, Tadcaster, September 1879; Messrs. E. Shackleton and Sons, Carlow, November 1879.

It had been alike difficult to eradicate both the original prejudice that for finishing certain qualities of flour the porous millstone was indispensable, and the subsequent assertion that at least the more or less porous texture of the porcelain roller mill was required.

(Mr. Simon.)
Ultimately however the present well-established fact had been admitted, that cast-iron chilled rollers if properly used gave results in every way superior to any that could be obtained either by the millstone or by the porcelain roller.

The relative nutriment contained in white or dark flour had thus far been largely a matter of opinion in this country, few if any reliable experiments having been made by careful diet of particular persons. At the university of Munich however it had been proved, as the result of extended experiments made by Professor Voit, that well baked white bread was assimilated by man almost in its entirety, and certainly to a much greater extent than any dark or whole-meal bread, of which a large percentage was rejected by his digestive organs. Moreover it appeared probable that a kind of rasping action was exercised on the intestines by the branny particles, which were the cause of the dark colour in brown and whole-meal bread. Although the irritation thus occasioned had medicinally the useful effect of obviating a costive tendency, yet it caused great waste, not only of undigested bread, but also of other valuable nutriment eaten at the same meal, and hurried through the digestive organs by this irritating action before there had been time for its digestion to be completed. Dark and whole-meal bread had a flavour of its own, which many persons liked for a change; but its general introduction as an article of food for the population at large he believed would be a retrograde step. In this connection the mistake was sometimes made of confounding chemical analysis and the contents of the retort with the practical results attained by man's digestive organs: while the fact was overlooked that unfortunately the branny particles, which contained a large percentage of highly glutinous matter attached to their inner surface, were themselves wholly indigestible by man, and were forthwith rejected; whereas in the retort they counted as increasing the percentage of nutriment. It was therefore much better to give these branny particles to cattle, in order that by their superior and longer digestive organs they might be transformed into meat, instead of sending them to waste through the human body.

MEMOIRS.

William Bawden was born in the parish of Gwennap, near Truro, on 15th July 1824. In the following year his family removed from Cornwall to the Mold Mines in Flintshire, of which his father was the mining engineer. In 1840 he commenced his apprenticeship, on the completion of which in 1845 he undertook the management of the Coed Talon Iron Works in that vicinity. Leaving there in 1847, he became principal draughtsman to Messrs. Garnett and Moore, Liverpool, with whom he remained till 1850, when he went to Messrs. Benjamin Hick and Sons, Bolton, in the same position of principal draughtsman. At the end of 1865 he joined the Boiler Insurance and Steam Power Company, Manchester, as one of their assistant engineers, and continued in their service until the date of his death on 4th December 1888, at the age of sixty-four. He became a Member of this Institution in 1881.

Thomas Hindmarsh was born at Alnwick, in Northumberland, on 9th September 1827. In 1844 he was apprenticed to Mr. John Dewrance for a period of five years, during which time he was engaged under him in the locomotive department of the Liverpool and Manchester Railway, the Great Southern and Western Railway of Ireland, and the Midland Great Western Railway of Ireland. During 1849–50 he was employed for eighteen months under Mr. Chesterman on drainage works on the Kings Weston estate, Somersetshire. In 1851 he entered the Great Northern Railway locomotive department under Mr. Sturrock, where he remained four years. In 1855 he went to India to the Eastern Bengal Railway, where he commenced in the running department, and gradually rose until in 1866 he was appointed chief locomotive superintendent. This position he held until 30th September 1884, when he resigned it in consequence of the Indian State Railways having taken over

the Eastern Bengal system. In 1888 he returned to India as the representative of the automatic vacuum brake, and did much to secure its adoption for the Indian State Railways. He died off Aden on 8th February 1889, in the sixty-second year of his age, while on his way back to England. He became a Member of this Institution in 1885.

WILLIAM LYSTER HOLT was born in London on 15th August 1839; and after being educated in France and at King's College School, London, served a pupilage from 1853 to 1857 to Mr. M. C. Rea at the locomotive works of the Great Western Railway, Swindon, where he passed through all the shops, and was employed for one year as draughtsman, and for a part of the time had charge of the running sheds at Reading. During 1859–60 he was third and second engineer in the s.s. "Earsdon" and the "Admiral Kanaris." Then for two years, 1861–62, he studied civil engineering and the higher branches of mathematics at the New Cross Naval School and at University College, London. For eighteen months, 1863–64, he was employed by Messrs. Buchanan and Co. in designing various classes of machinery, and in supervising the construction of a large paddle yacht for the King of Siam. In 1864–65 he was engaged as manager and senior draughtsman to Mr. Robert F. Fairlie on general railway work, and in perfecting the details for his double bogie locomotive. He then became assistant engineer to the Central Railway of Venezuela, and was occupied in preparing designs for bridges, girders, &c., and in generally superintending and inspecting all the ironwork and rolling stock for that railway. In 1866 he was resident engineer and locomotive superintendent on the Neath and Brecon Railway, 33 miles long, then in course of construction; and assisted generally in designing and superintending the manufacture and erection of girders and bridges, engine sheds and appliances, and in the design of the rolling stock. For nine years, 1868–77, he was in partnership with Mr. G. O. Budd, and amongst other works was engaged in fitting out the steam yacht "Stella" for the Duke of Hamilton, as well as in designing and superintending the construction of a large T-head to the jetty at the New Dundee Wharf, Wapping,

and in superintending the construction as contractor's engineer of the following railways:—St. Aubin's and La Moye Railway, Jersey, 4 miles; Malmesbury Railway, $6\frac{1}{2}$ miles; and Bury and Thetford Railway, 13 miles. In 1877 he was appointed chief engineer on the Southern Tramway in Paris, over 50 miles in length, and had charge of the steam traction, employing over thirty locomotives; he also supervised the Rouen steam tramways. In 1878 he gave evidence before a committee of the House of Commons in regard to the use of mechanical power on tramways; and also acted as one of the jurors at the International Exhibition, Paris; and in 1879 he accompanied General Hutchinson in his official inspection of the Rouen and Paris tramways. From the commencement of 1880 he practised on his own account as a civil engineer, and was principally engaged in obtaining parliamentary sanction for more than 120 miles length of steam and horse street-tramways, and in superintending their execution and equipment. In 1883–84 he acted as engineer to the Duke of Portland for the drainage of Welbeck Abbey gardens. In 1885 he was one of the jurors of the Inventions Exhibition, London. Latterly he was engaged in superintending the equipment of the steam tramways in Accrington, and the construction and equipment of those in Blackburn. His death took place in London on 11th February 1889, in the fiftieth year of his age. He became a Member of this Institution in 1867.

JAMES HOWARD, of Clapham Park, Bedfordshire, senior partner in the firm of Messrs. James and Frederick Howard, Britannia Iron Works, Bedford, was born at Bedford on 16th October 1821, being the eldest son of Mr. John Howard, founder of the business, who held the office of mayor in his native borough four years in succession. He was educated at the Bedford schools, and from his boyhood manifested a fondness for mechanics. At the age of twenty he introduced a plough of his own design, made entirely of iron and steel, which he exhibited at the Royal Agricultural Society's show at Liverpool in 1841; and being unable to find a ploughman acquainted with a wheel-plough, he took the handles himself, and steered his course so successfully as to win the first prize. Possessing great

mechanical skill, he effected many improvements in agricultural implements and machinery, including ploughs, harrows, horse-rakes, self-delivery reapers, hay-makers, machinery for tilling land by steam power, mowers, sheaf-binders, straw-trussers, in addition to his inventions of moulding machines, and steel sleepers and chairs for permanent and portable railways. His mechanical skill was early exemplified by his invention in April 1852 of a method of chilling cast-iron; and again in 1870 by the introduction of the tubular safety boiler known by his name (Proceedings 1872 page 278); indeed to the end of his life he was busy with new inventions.

Having previously contributed valuable aid in the promotion of improvements in Bedford, he was three times elected mayor; and during his mayoralty a comprehensive scheme of drainage, water-supply and sewage utilization was inaugurated; while to his ingenuity and sagacity it was owing that Bedford was the first place to be sewered on the separate system, whereby the storm-water and the sewage are kept apart in their flow through the public sewers.

Of his many publications on economical questions the following may be mentioned:—"Agricultural machinery and the Royal Agricultural Society," 1857; "Labour and wages, and the effect of machinery upon them," 1859; "Steam culture, its history and proper application," 1862; "Trip to America," 1867; "Visit to Egypt," 1867; "Scheme of national education for rural districts," 1868; "Continental farming and peasantry," 1870; "Our villages, their sanitary condition," 1874; "Our meat supply," 1876; "Depression in agriculture," 1879; "Agricultural implement manufacture, its rise and progress," 1879; "Laying down land to grass," 1880; "English land question, past and present," 1881. He became a Member of this Institution in 1860, and was also a prominent member of various other public societies, having served as President of the Association of Agricultural Engineers, as well as of the Farmers' Alliance and of the London Farmers' Club. For many years he was a director of the Agricultural Hall, Islington, London, in the erection of which he was mainly instrumental. He was also an active member of the council of the Royal Agricultural Society, and chairman of the Bedford and Northampton Railway. He represented Bedford in

parliament from 1868 to 1874, and Bedfordshire from 1880 to 1885. Of this county he was a magistrate and deputy-lieutenant, and in 1879 filled the office of high sheriff. His death occurred in London on 25th January 1889, at the age of sixty-seven; and it was only in the previous week he had been returned unopposed to the first Bedfordshire County Council.

RICHARD PEACOCK, M.P. for Gorton, was born on 9th April 1820 at the village of Swaledale in the North Riding of Yorkshire. He was the seventh son of Mr. Ralph Peacock, who was at one time a lead miner, and rose to the position of overseer of several mines in the neighbourhood of Swaledale, and subsequently became assistant superintendent in the construction of the Leeds and Selby Railway. Richard Peacock's education was continued at the Leeds Grammar School, and on leaving school at the age of fourteen he was apprenticed to Messrs. Fenton, Murray and Jackson of Leeds, who were at that time constructing locomotives for the Liverpool and Manchester and the Leeds and Selby Railways, as well as other steam engines and pumps and hydraulic machinery. He was placed directly under the charge of Mr. Jackson, the managing partner of the firm; and remained with them until 1838, when he was appointed at the age of eighteen locomotive superintendent of the Leeds and Selby Railway. This position he held with credit to himself and advantage to the railway until the line was amalgamated with the York and North Midland Railways in 1840. The head quarters of the locomotive department were then removed from Leeds to York, and he was invited to take charge of the locomotive department there under Mr. Cabry. Desiring wider experience however, he went to the Great Western Railway Works, then in progress under the direction of Mr. Brunel, where he remained until in 1841 he was appointed locomotive superintendent of the Manchester and Sheffield Railway, which was then nearing completion. Upon this new duty he entered at the age of twenty-one, shortly before the delivery of the first locomotive to the line. For fourteen years he continued in this position, during which time the undertaking largely increased in extent and importance. During his charge, the

selection of the most suitable site for the railway workshops and main locomotive depôt devolved upon him; and at Gorton near Manchester, in accordance with his designs and under his direction, the large and important works of the railway were laid out, of which he gave a description to this Institution (Proceedings January 1851, page 22). In 1849 he was made a Member of the Institution of Civil Engineers.

In 1854 he entered into partnership with the late Mr. Charles Beyer, as locomotive and machine-tool makers at Gorton, where they purchased fourteen acres of land close to the railway works with which he had been so long associated; in May 1854 the first sod was turned, and within twelve months afterwards the first engine was turned out. Looking well ahead they designed a series of workshops for covering the whole fourteen acres; and with that plan in view they set to work to build such portions as their means permitted. The various sections of the works are today almost counterparts of one another, so far as the buildings are concerned, having been so arranged as to admit of gradual expansion by the simple addition of other sections, without disturbing the portions previously erected. Their first locomotives were made for the Great Western Railway; and building after building was erected until the whole of the site became utilised. Mr. Peacock did good work in developing the locomotive engine in its earlier days, being specially associated with experiments in connection with the blast pipe; his experiments and deductions are fully recorded in Mr. D. K. Clark's work on "Railway Machinery." But it was more as an organiser and a judge of men, and as possessing an almost intuitive mastery of financial questions, that his talents were seen, than as an inventor. He took an active part in local matters, and identified himself with any movement tending to the progress and prosperity of the neighbourhood. He was elected the first chairman of the local board of the Gorton district, and continued to hold that position until 1866, when the pressing calls of business compelled him to resign. He was president of the Openshaw Gorton and Bradford Mechanics' Institute from the time of its opening to his death. In 1885, when the newly created parliamentary division of Gorton was

called upon to choose a representative, he was elected its member, and continued to represent the constituency until his death. He was also a justice of the peace for the county of Lancaster.

He was one of the original Members of this Institution at its establishment in 1847, and for many years a Member of Council and a Vice-President. Besides the description already mentioned of the railway locomotive works at Gorton, he also gave a description of a steam hammer used at Gorton Foundry for light forgings (Proceedings 1860 page 284). His death took place at his residence, Gorton Hall, on 3rd March 1889, in the sixty-ninth year of his age, after a lingering illness.

FRANK SALTER, younger son of the Rev. W. A. Salter, of Amersham and Leamington, was born on 19th October 1848, and was educated at Amersham Hall School and University College, London, ultimately graduating as Bachelor of Science, London. He served his apprenticeship in the workshops of the London and North Western Railway at Crewe in 1868 and 1869; and gained a Whitworth scholarship in 1870, the second year in which those scholarships were given, for which he competed as a workman. In 1871 he was in Newcastle with Messrs. Clark Watson and Gurney; from whom he went for a short time to Messrs. Gwynne, of Hammersmith. From 1874 until 1881 he was manager of Messrs. Bryan Donkin and Co.'s works at Bermondsey; and on the reconstruction of that firm he acted as managing partner in the works, until the failure of his health in the autumn of 1887. With the exception of a short time in the following summer, he was unable to resume work; and his illness terminated fatally on 31st December 1888, at the age of forty. He became a Member of this Institution in 1887. To the Institution of Civil Engineers he contributed a paper on economy in the use of steam; and in conjunction with Mr. Bryan Donkin, Jun., papers on some trials of a rotative pumping engine, and on the measurement of water over weirs. An extensive series of experiments on the small steam engine now in the engineering laboratory of University College, London, was made by him together with Mr. Bryan Donkin, Jun., and Mr. B. W.

Farey, in 1874–1881, the results of which were published in "Engineering" in November and December 1886.

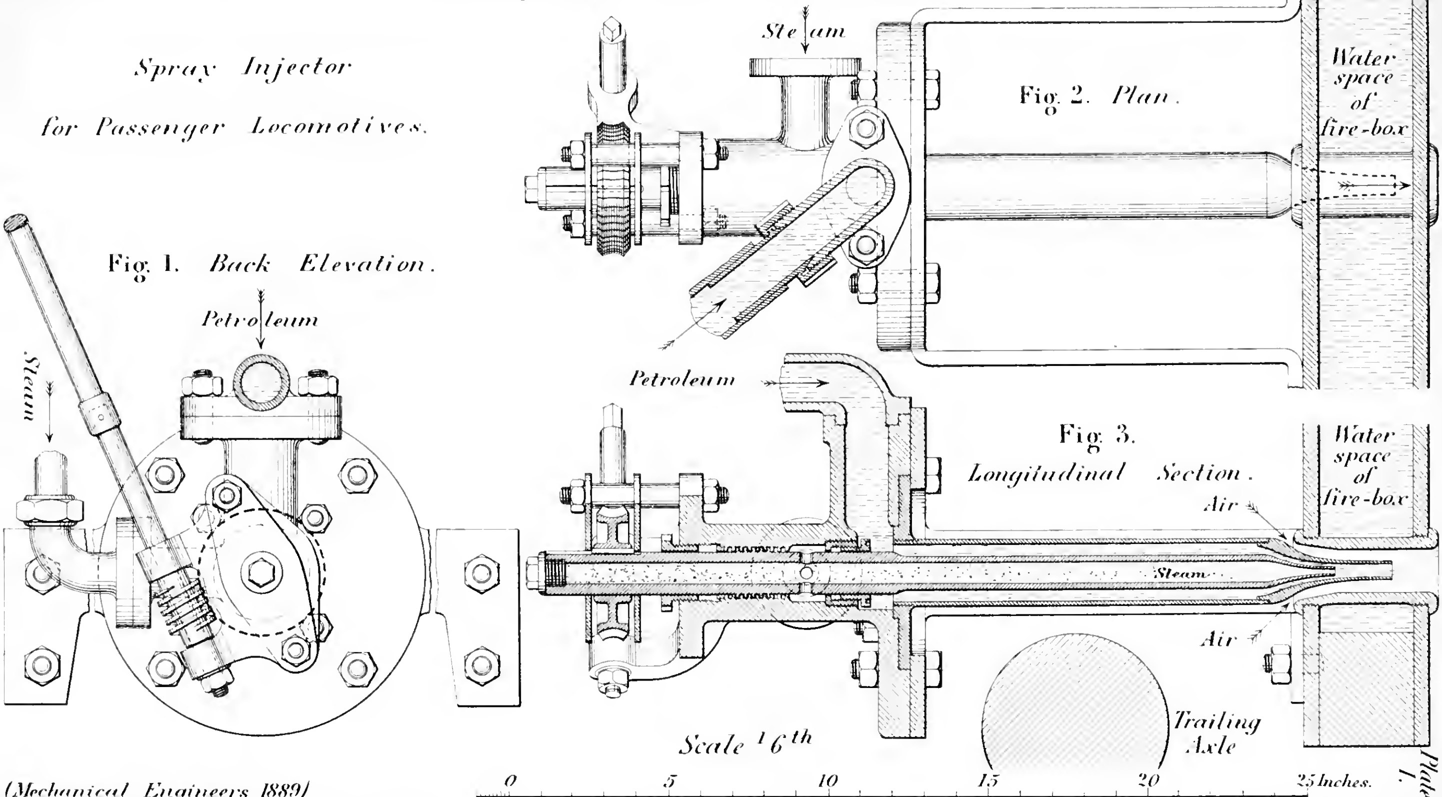
Charles Henry Turnbull, son of Mr. Joseph Turnbull, was born in Manchester on 23rd October 1845. In 1861 he entered upon a five years' apprenticeship in the millwrights', engineering, and hydraulic departments of the Mersey Dock and Harbour Board. He subsequently served at Messrs. Laird Brothers, Birkenhead, at the Crewe Works of the London and North Western Railway, at Messrs. Forrester and Co.'s, Vauxhall Foundry, Liverpoool, and at Messrs. D. and C. Maciver's, Cunard Steamship Works, Liverpool. From 1872 he acted as foreman millwright and chief assistant to his father, the chief supervisor and constructor of machinery on the Mersey Dock Estate, Liverpool. His death occurred on 18th December 1888, at the age of forty-three, at Gijon in Spain, where he had been sent about five months previously to erect an 80-ton hand crane. He became a Member of this Institution in 1883.

Captain Harry Borlase Willock, R.E., was born at Tenby on 6th March 1854, and was educated at Cheltenham College, whence he passed into the Royal Military Academy in December 1870; and in 1872, having obtained a commission as lieutenant in the Royal Engineers, he proceeded to the School of Military Engineering at Chatham. In 1876 he went to Bermuda, where he served with the 10th Company, Royal Engineers, and was employed for nearly two years in connection with the works for the defence of the new dockyard and naval anchorage. Returning to England, he joined the 2nd Co. R.E. at Shorncliffe, and in December 1878 proceeded with them to South Africa. There he served in the earlier part of the Zulu war with Colonel Pearson's column, and was present in the action at Inyezane on 22nd January 1879 and throughout the occupation of Ekowe; he was mentioned in despatches in the "London Gazette" 16th May 1879, and received the medal and clasp. On his return to England he was appointed to take charge of the workshops at the School of Military Engineering, and from thence went to the works department of the Royal Arsenal, Woolwich, under Colonel W. H. Noble, R.E.,

and subsequently under Colonel Crozier, R.E., where under his care a considerable portion of the railways in the arsenal were re-arranged and relaid, a work much required owing to the extension of the factories and the greatly increased loads that had to be moved. In 1882 on the outbreak of the Egyptian war he was appointed to assist in the railway transport, and prior to embarkation was engaged at Woolwich Arsenal in collecting and shipping railway material and plant. He sailed for Egypt in August of that year, and on arriving at Ismailia superintended the unloading of the stores; he was afterwards left in charge during the rush of traffic to Cairo, and at the conclusion of the campaign collected and accounted for all railway stores. For these services he received the medal and bronze star. Returning to England at the end of 1882 he was placed on the staff of the inspector of iron structures at the War Office, and there assisted in the designing and construction of all machinery required in connection with the coast defences, and in the supply of material and general supervision of military railways in this country and in Egypt and the Soudan. For the latter service he was officially commended by the inspector-general of fortifications. In December 1887, he was appointed inspector of iron structures, as successor to Major English, R.E.; and in this capacity completed the erection and tests of the 112-ton hydraulic traveller at Shoeburyness, and designed the details of the 250-ton pontoon sheers now in course of construction. He acted as secretary to the committee on the preparation of the "Military railway manual," and also to the committee on the preparation of "Instructions for the care and maintenance of war department boilers." In the somewhat laborious calculations involved in obtaining the results given by Major English in his paper before this Institution on experiments on the distribution of heat in a stationary steam-engine (Proceedings 1887 page 486) he rendered much valuable assistance. He died at his father's house at Tenby on 6th February 1889, after a very short illness, in the thirty-fifth year of his age. He became a Member of this Institution in 1884.

PETROLEUM FUEL IN LOCOMOTIVES.

Spray Injector for Passenger Locomotives.



(Mechanical Engineers 1889)

PETROLEUM FUEL IN LOCOMOTIVES.

Plate 2.

Combustion Chamber: Six-wheeled Goods and Passenger Engines.

Fig. 4. *Sectional Plan.*

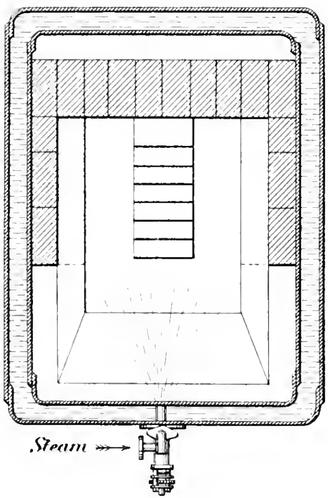


Fig. 5. *Transverse Section.*

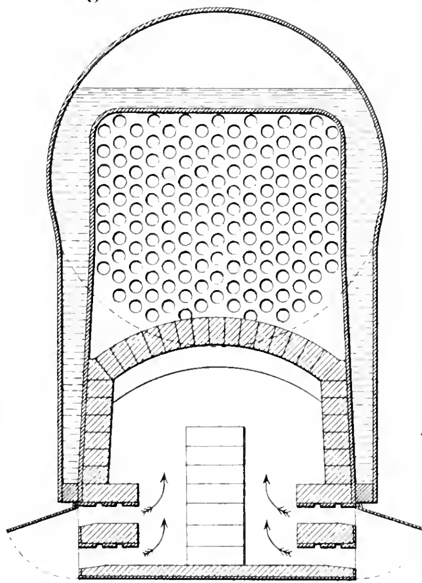
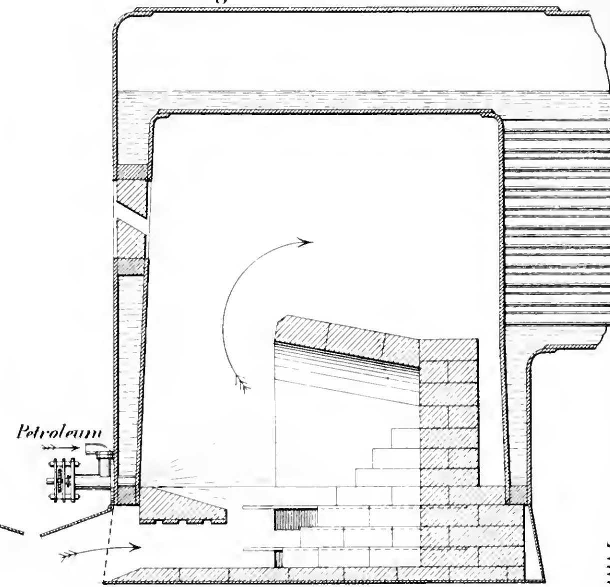


Fig. 6. *Longitudinal Section.*



(Mechanical Engineers 1889)

Scale 1/30th.

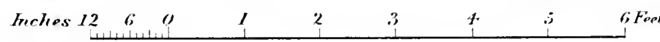


Plate 2.

PETROLEUM FUEL IN LOCOMOTIVES.

Combustion Chamber. Eight-wheeled Goods Engines.

Fig. 7. *Sectional Plan.*

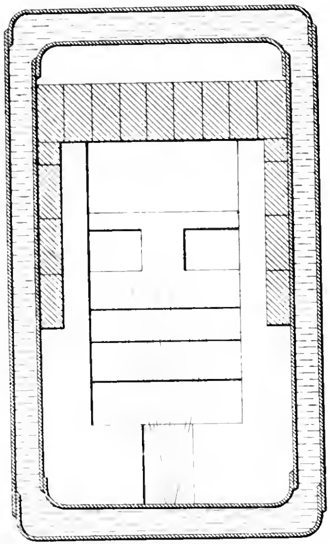


Fig. 8. *Transverse Section.*

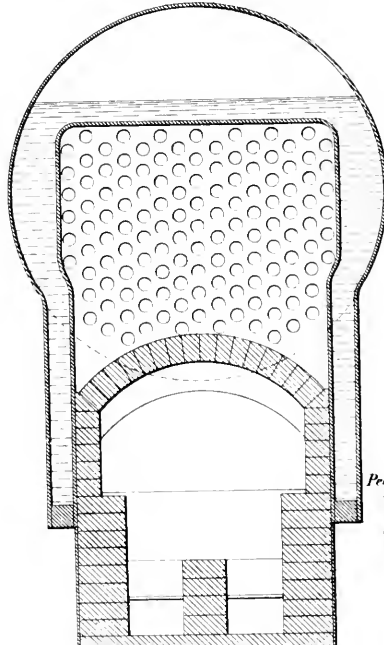
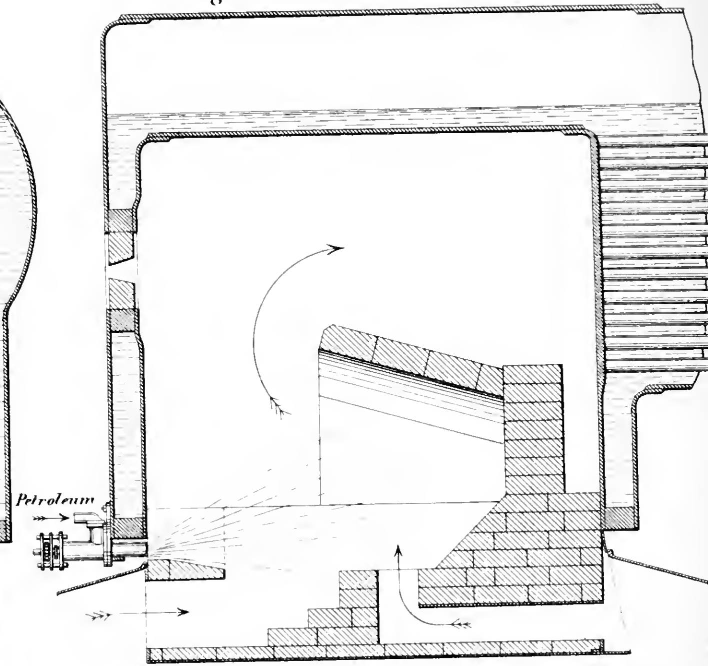


Fig. 9. *Longitudinal Section.*



Scale 1/30th

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet.

(Mechanical Engineers 1889)

PETROLEUM FUEL IN LOCOMOTIVES.

Plate 4.

Galloway and Marine Boilers.

Fig. 10. *Sectional Plan.*

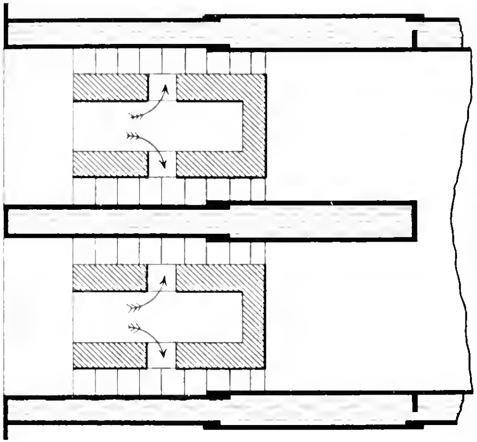


Fig. 11. *Transverse Section.*

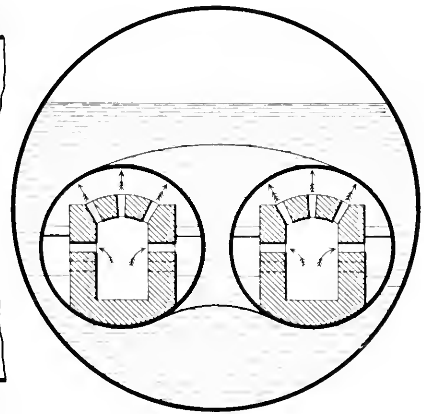
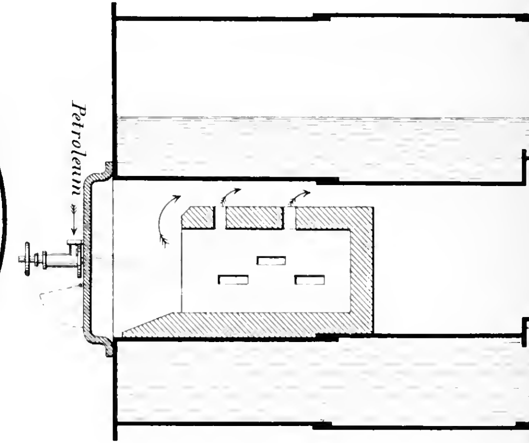


Fig. 12. *Longitudinal Section.*



Scale 1/40th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet

(Mechanical Engineers 1889)

Plate 4.

PETROLEUM FUEL IN LOCOMOTIVES.

Horizontal Boiler fired underneath.

Fig. 13. *Sectional Plan.*

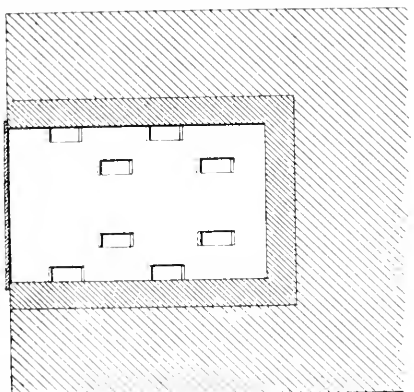


Fig. 14. *Transverse Section and End Elevation.*

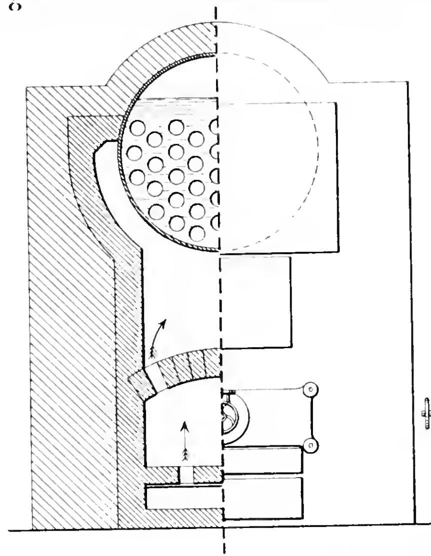
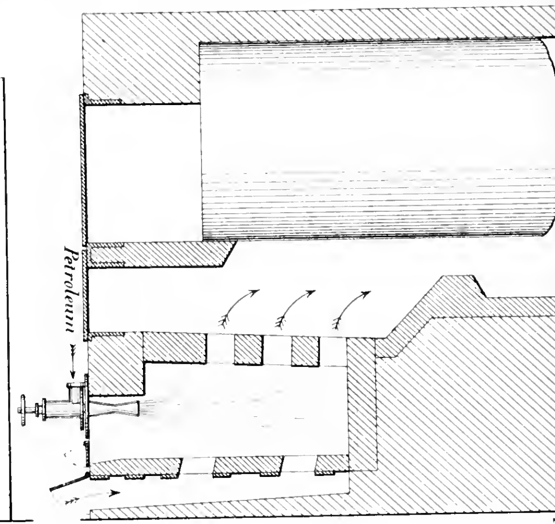


Fig. 15. *Longitudinal Section.*



Scale 1/30th

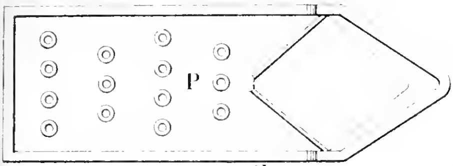
(Mechanical Engineers 1889)

Plate 5.

PETROLEUM FUEL IN LOCOMOTIVES. *Plate 6.*

Vertical Boiler.

Fig: 20. *Plan of Pan.*



Scale 1/10th

Fig: 21. *Longitudinal Section.*

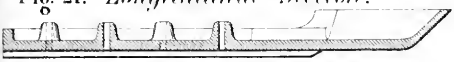


Fig: 18. *Plan with Pan removed.*

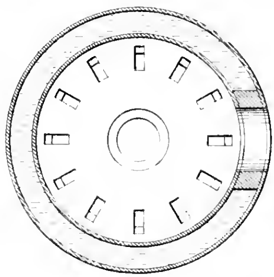


Fig: 16. *Plan with Pan inserted.*

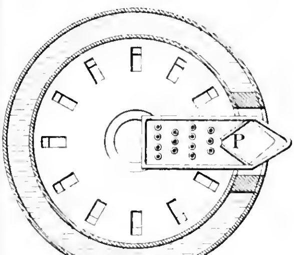
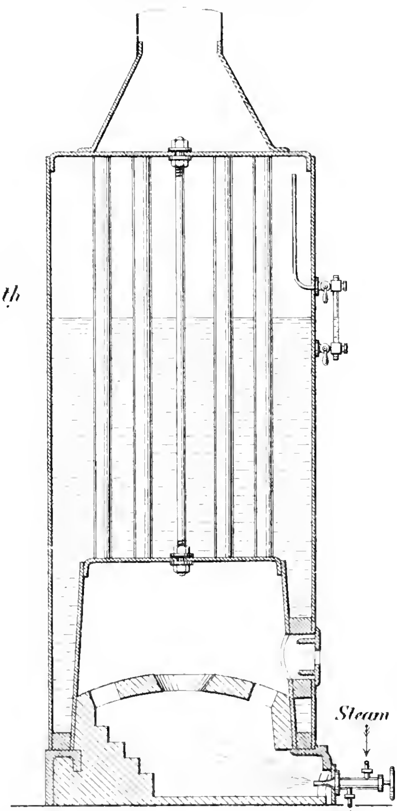
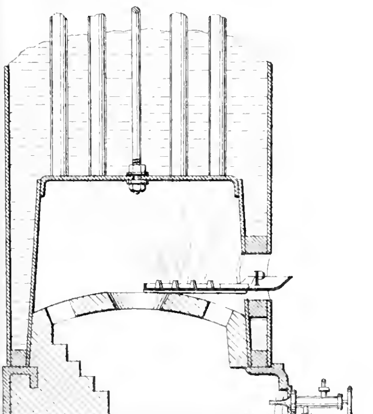


Fig: 19. *Vertical Section with Pan removed.*



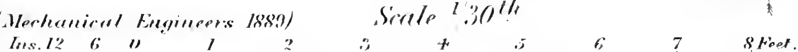
Scale 1/30th

Fig: 17. *Vertical Section with Pan inserted.*



(Mechanical Engineers 1889)

Scale 1/30th



PETROLEUM FUEL IN LOCOMOTIVES.

Combination Furnace for Petroleum and Wood firing.

Fig. 22. *Transverse Section.*

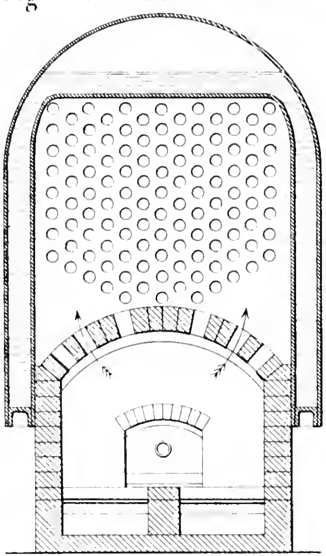


Fig. 23. *Longitudinal Section.*

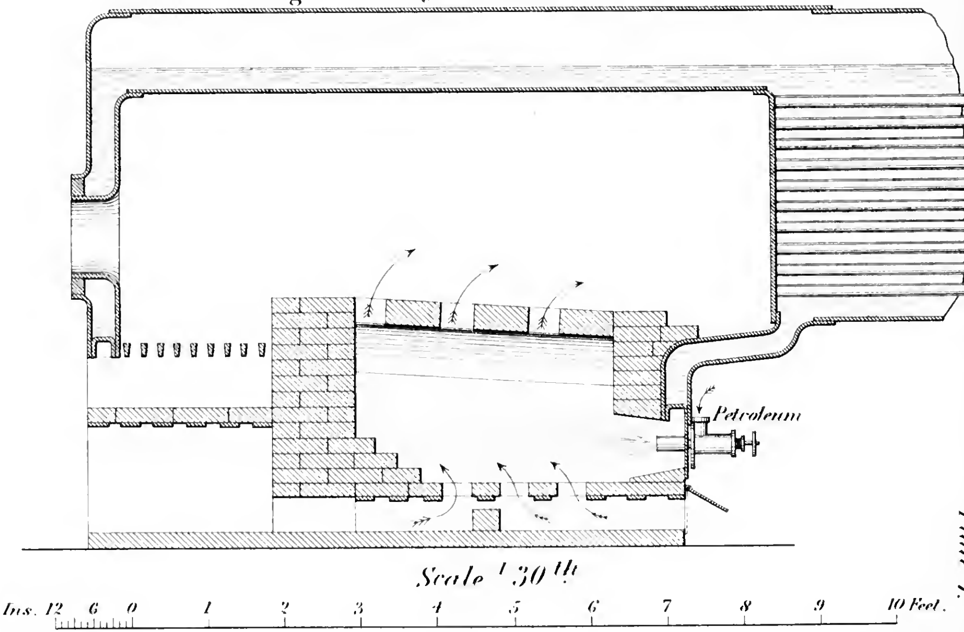
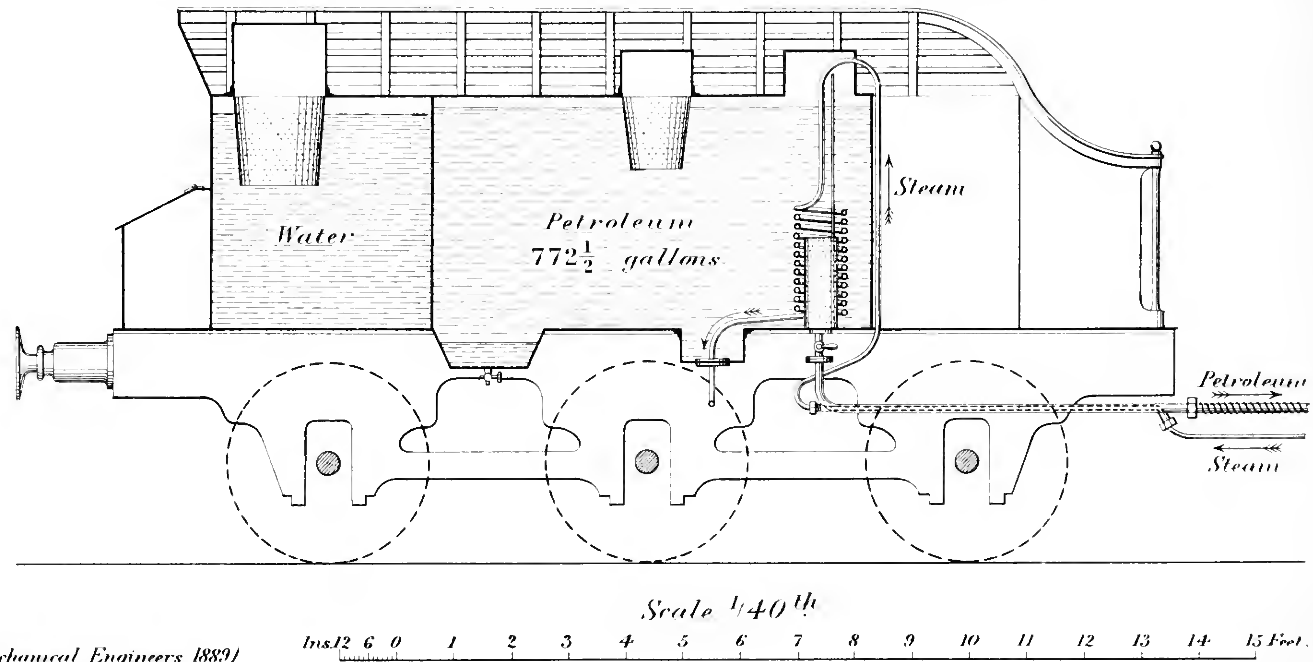


Plate 7.

(Mechanical Engineers 1889)

PETROLEUM FUEL IN LOCOMOTIVES.

Tender of Six-wheel Goods Locomotive. Fig. 24. *Longitudinal Section.*

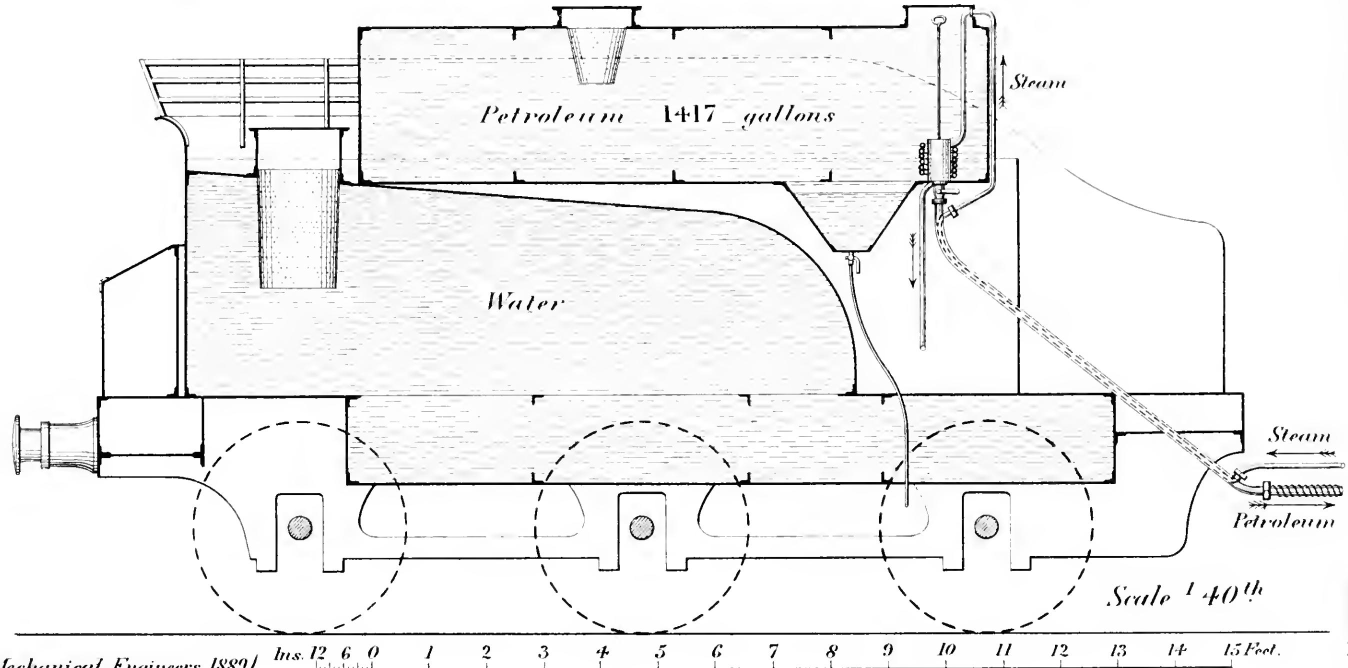


(Mechanical Engineers 1889)

Plate 8.

PETROLEUM FUEL IN LOCOMOTIVES.

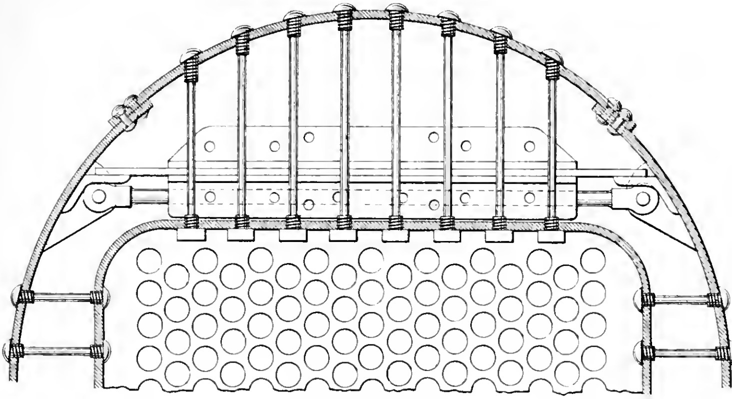
Tender of Eight-wheel Goods Locomotive. Fig: 25. *Longitudinal Section.*



(Mechanical Engineers 1889)

Plate 9.

Fig. 26. *Roof Stay-Bolts.*



Scale 1/16th.

Ins. 12 6 0 1 2 3 4 Feet.

Verderber Boiler.

Fig. 27.
Transverse Section.

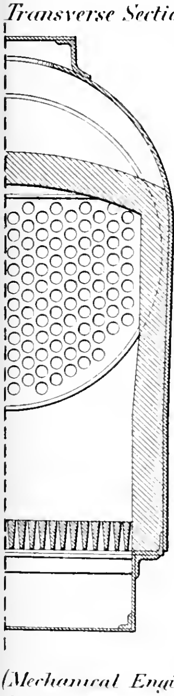
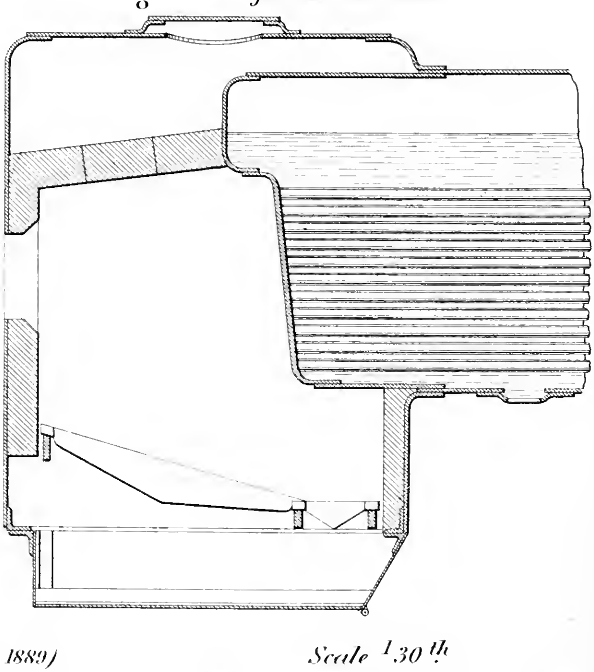


Fig. 28. *Longitudinal Section.*



(Mechanical Engineers 1889)

Scale 1/30th.

Inches 12 6 0 1 2 3 4 5 6 7 8 Feet.

PETROLEUM FUEL IN LOCOMOTIVES.

Modified Verderber Furnace, Six-wheeled Goods Engine.

Fig. 29. *Transverse Section.*

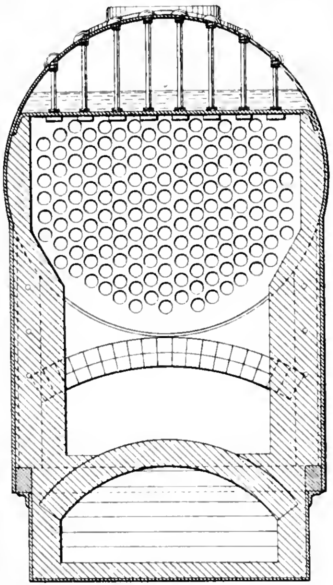


Fig. 30. *Sectional Plan.*

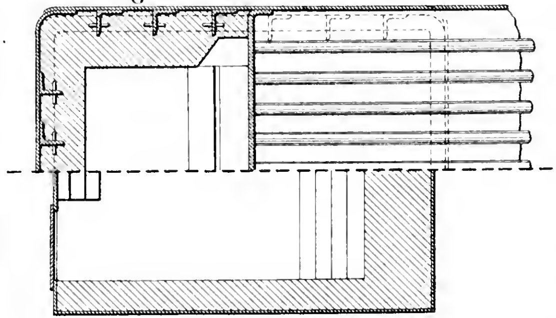


Fig. 31. *Longitudinal Section.*

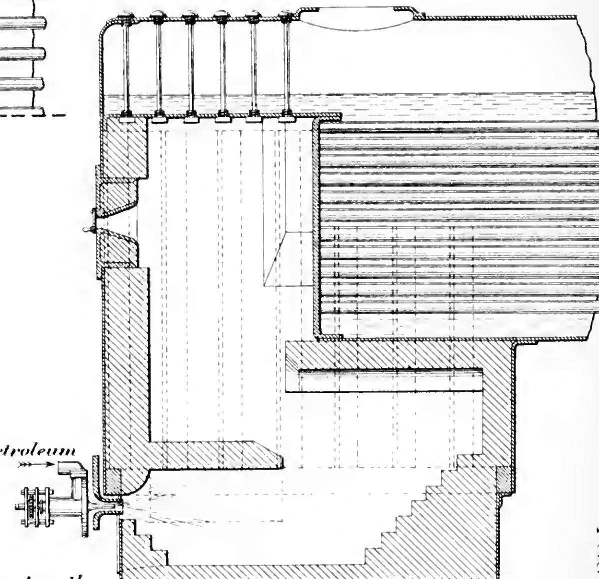
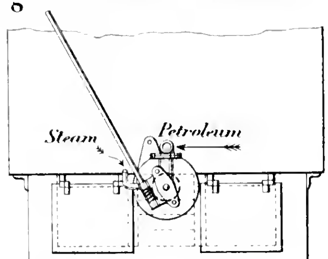


Fig. 32. *Back Elevation.*



Scale 1/30th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Mechanical Engineers 1889)

Plate 11.

PETROLEUM FUEL IN LOCOMOTIVES.

Modified Verderber Furnace. Passenger Engine.

Fig. 33. *Transverse Section.*

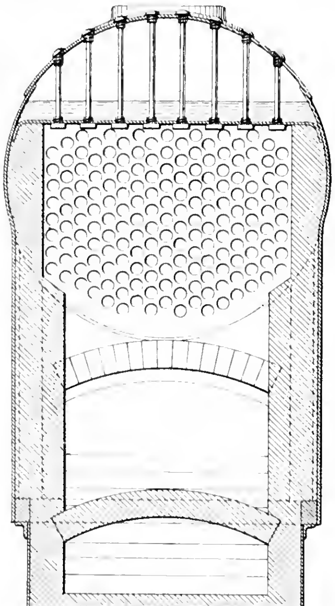


Fig. 34. *Sectional Plan.*

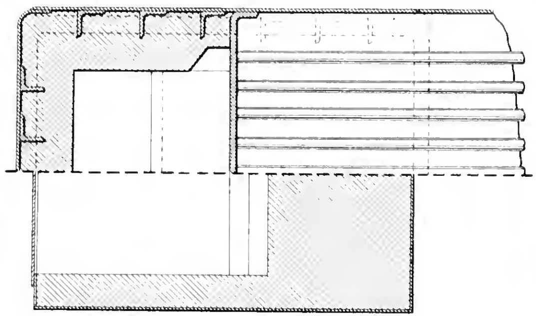


Fig. 35. *Longitudinal Section.*

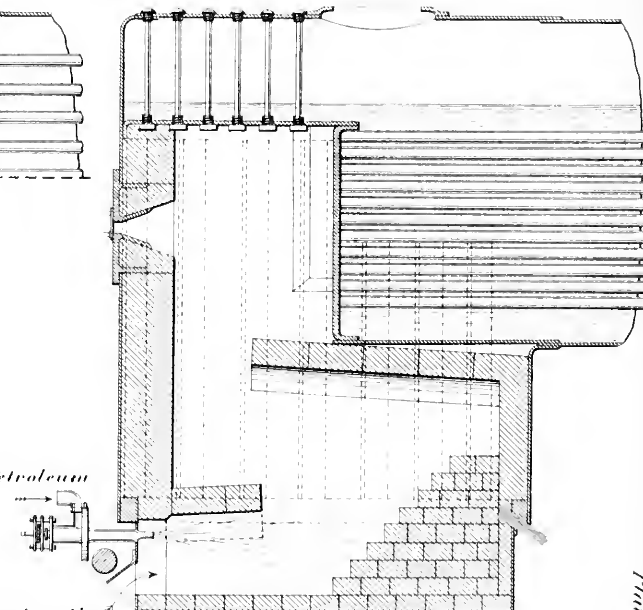
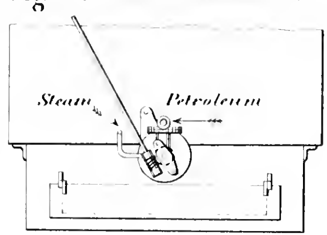


Fig. 36. *Back Elevation.*



Scale 1/30th

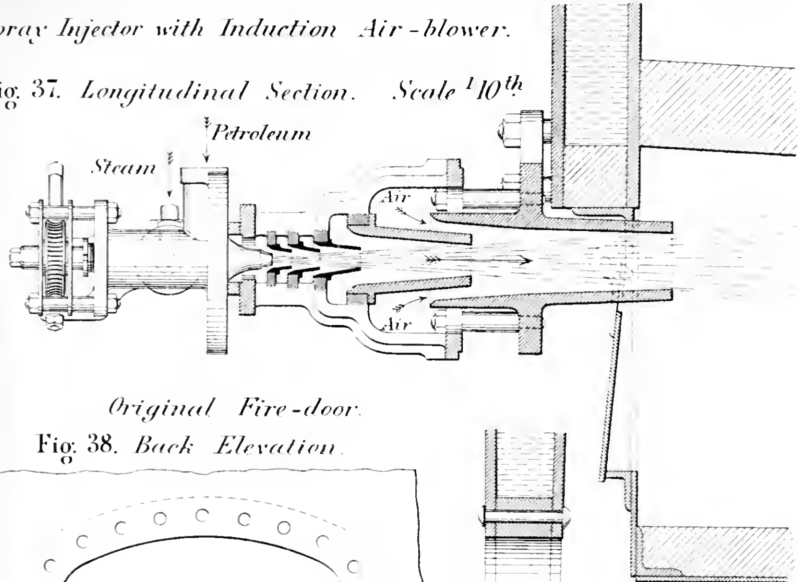
Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

(Mechanical Engineers 1889)

Plate 12.

Spray Injector with Induction Air-blower.

Fig. 37. *Longitudinal Section. Scale 1/10th*



Original Fire-door.

Fig. 38. *Back Elevation.*

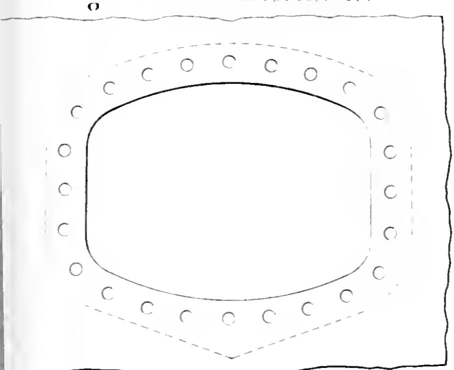


Fig. 39. *Vertical Section.*

Scale 1/12th

Plating up of Fire-door.

Fig. 40. *Back Elevation.*

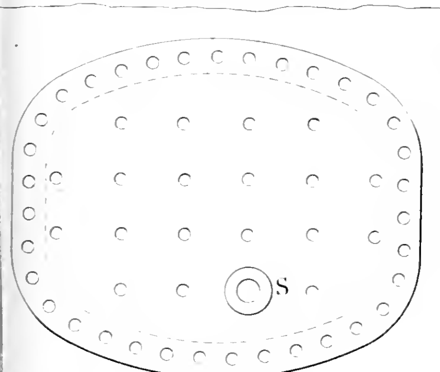


Fig. 41. *Old Fire-box.*

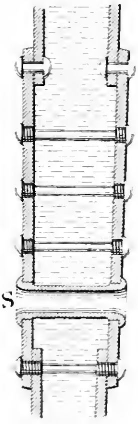
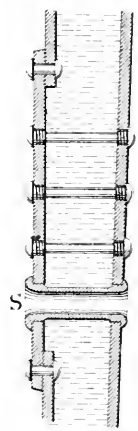


Fig. 42. *New Fire-box.*



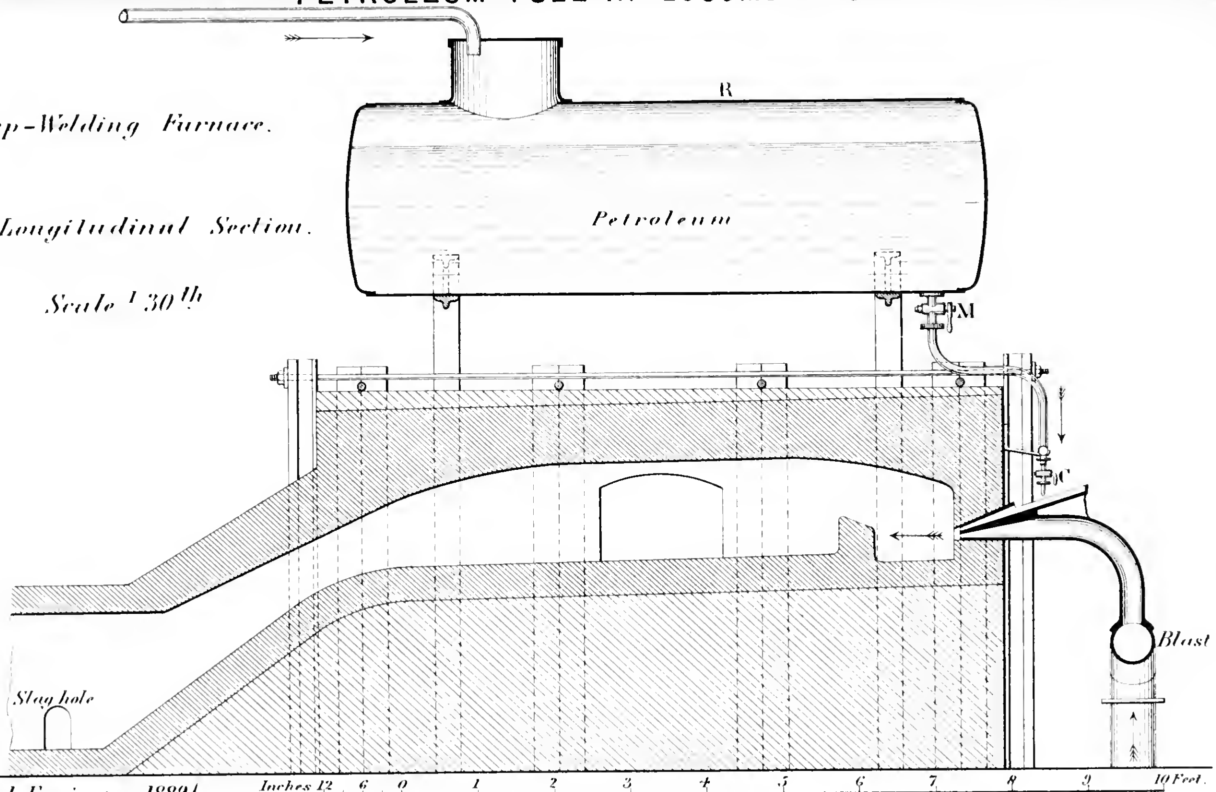
Scale 1/12th

Inches 12 6 0 1 2 Feet.

Scrap-Welding Furnace.

Fig: 43. *Longitudinal Section.*

Scale 1/30th



PETROLEUM FUEL IN LOCOMOTIVES.

Plate 15.

Scrap-Welding Furnace.

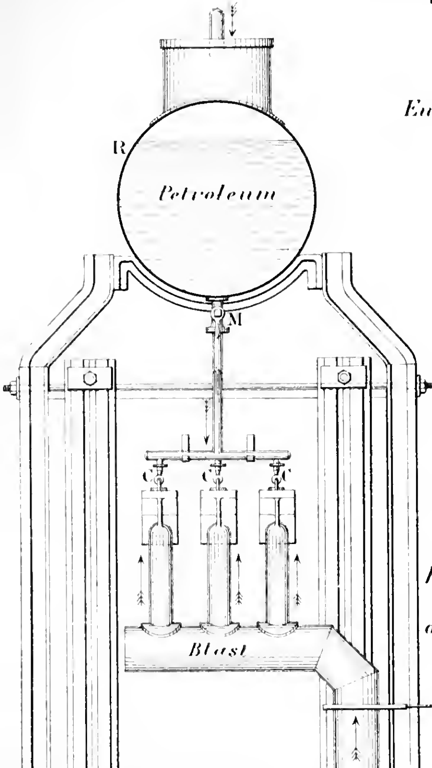


Fig: 44. *End Elevation of Furnace.* *Scale 1/30th.*

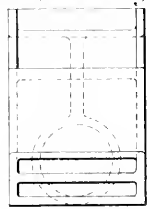


Fig: 45. *End View of Tuyere.* *Scale 1/8th.*

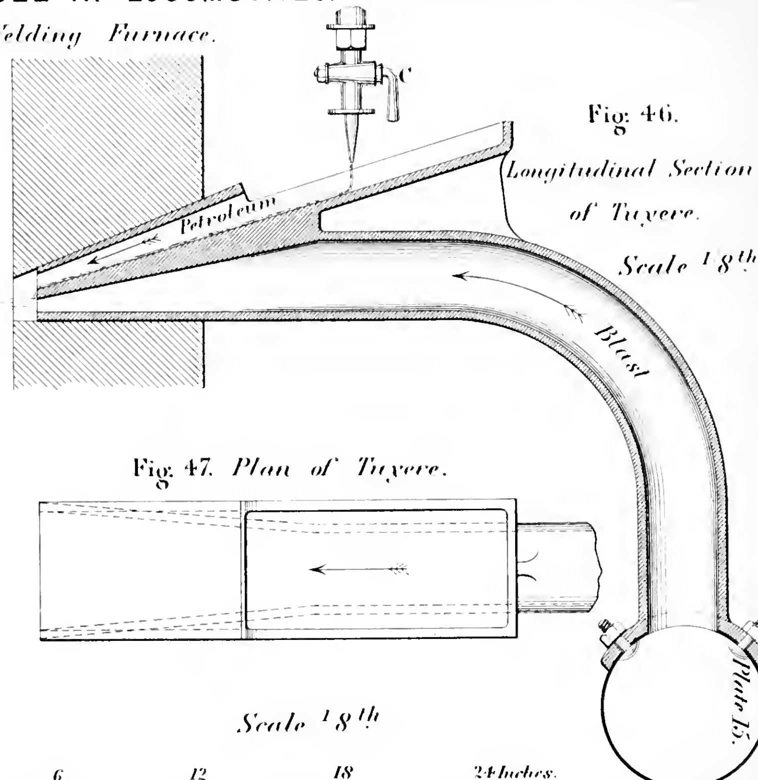


Fig: 46. *Longitudinal Section of Tuyere.* *Scale 1/8th.*

Fig: 47. *Plan of Tuyere.*

Scale 1/8th.

0 6 12 18 24 Inches.

(*Mechanical Engineers 1889*)

Brass – Melting Furnace.

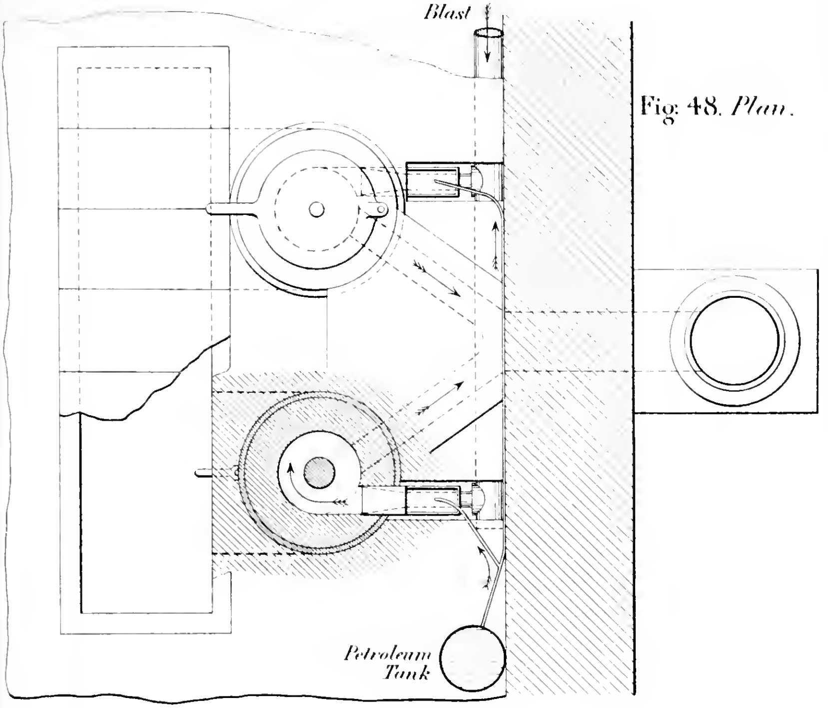


Fig. 48. *Plan.*

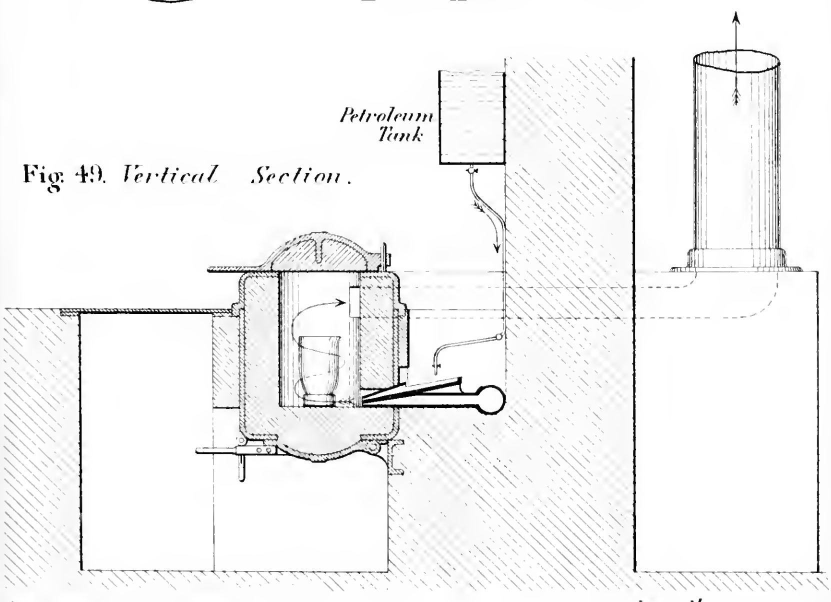


Fig. 49. *Vertical Section.*

(Mechanical Engineers 1889)

Scale 1/40th

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

PETROLEUM FUEL IN LOCOMOTIVES. Plate 17.

Profiles of Lines.

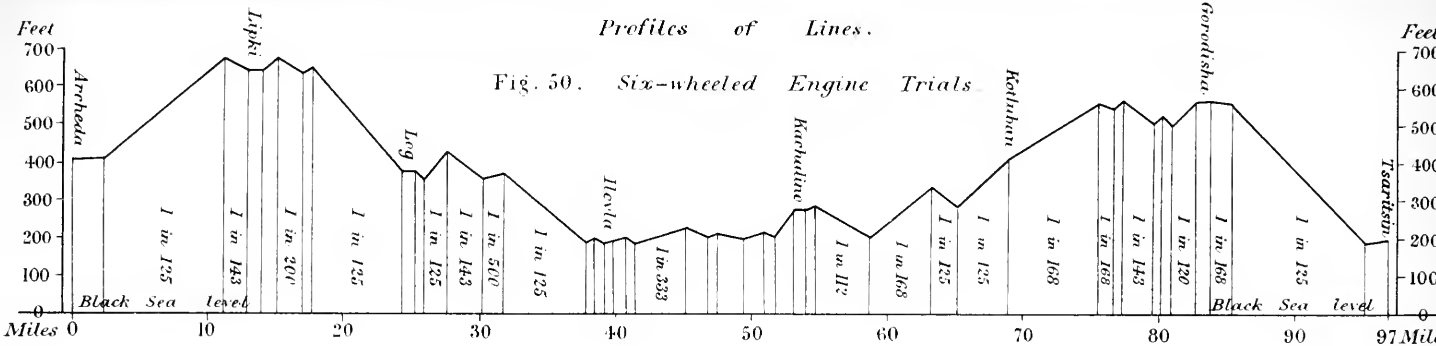
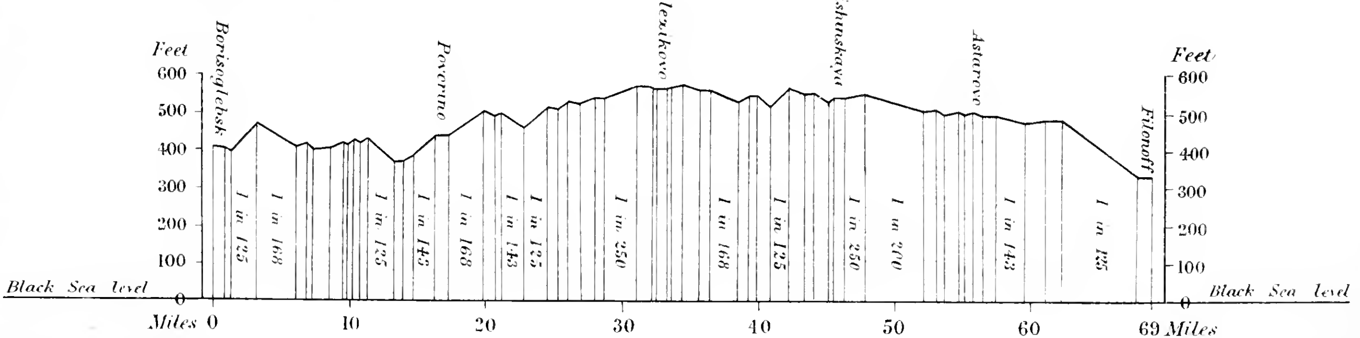


Fig. 50. *Six-wheeled Engine Trials.*

Fig. 51. *Eight-wheeled Engine Trials.*

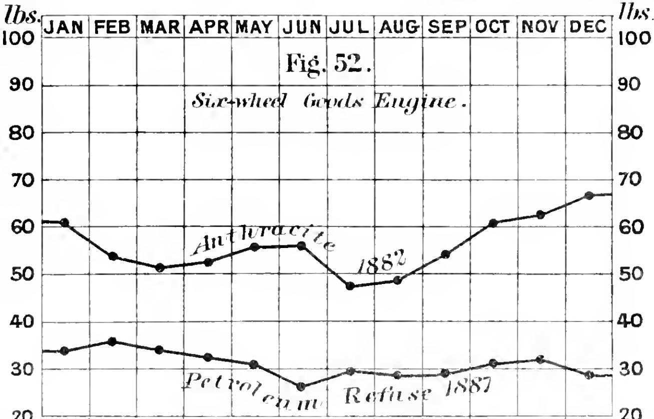


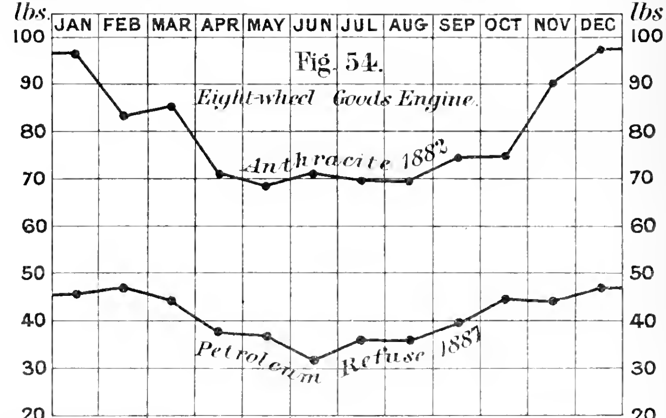
(Mechanical Engineers 1889)

Plate 17.

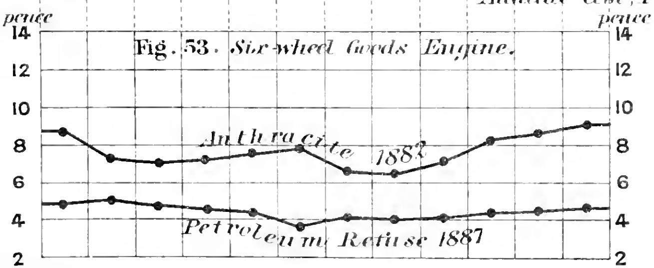
PETROLEUM FUEL IN LOCOMOTIVES.

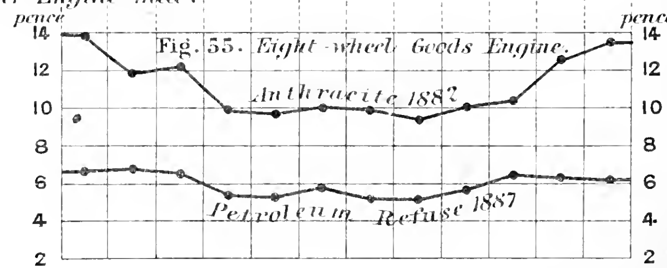
See Table XI. *Annual Consumption, Lbs. per Engine-mile.* *See Table XII.*





Annual Cost, Pence per Engine-mile.





(*Mechanical Engineers 1889*)

Fig. 56. *Cost of Fuel and of Engine and Tender Repairs.*

Shillings per 1000 *Axle-miles.* *See Table* XIV.

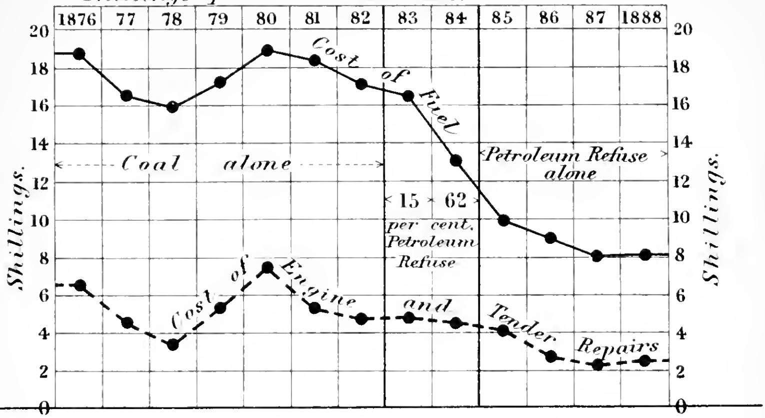
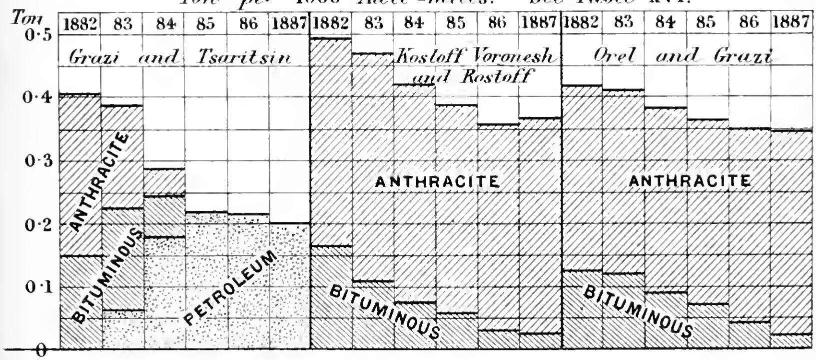


Fig. 57. *Consumption of Fuel* 1882-87 *on three neighbouring Railways.*

Ton per 1000 *Axle-miles.* *See Table* XVI.



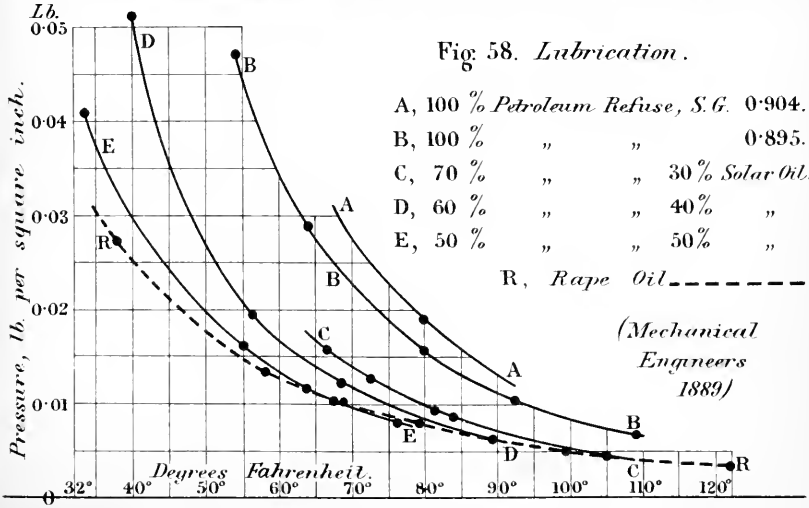
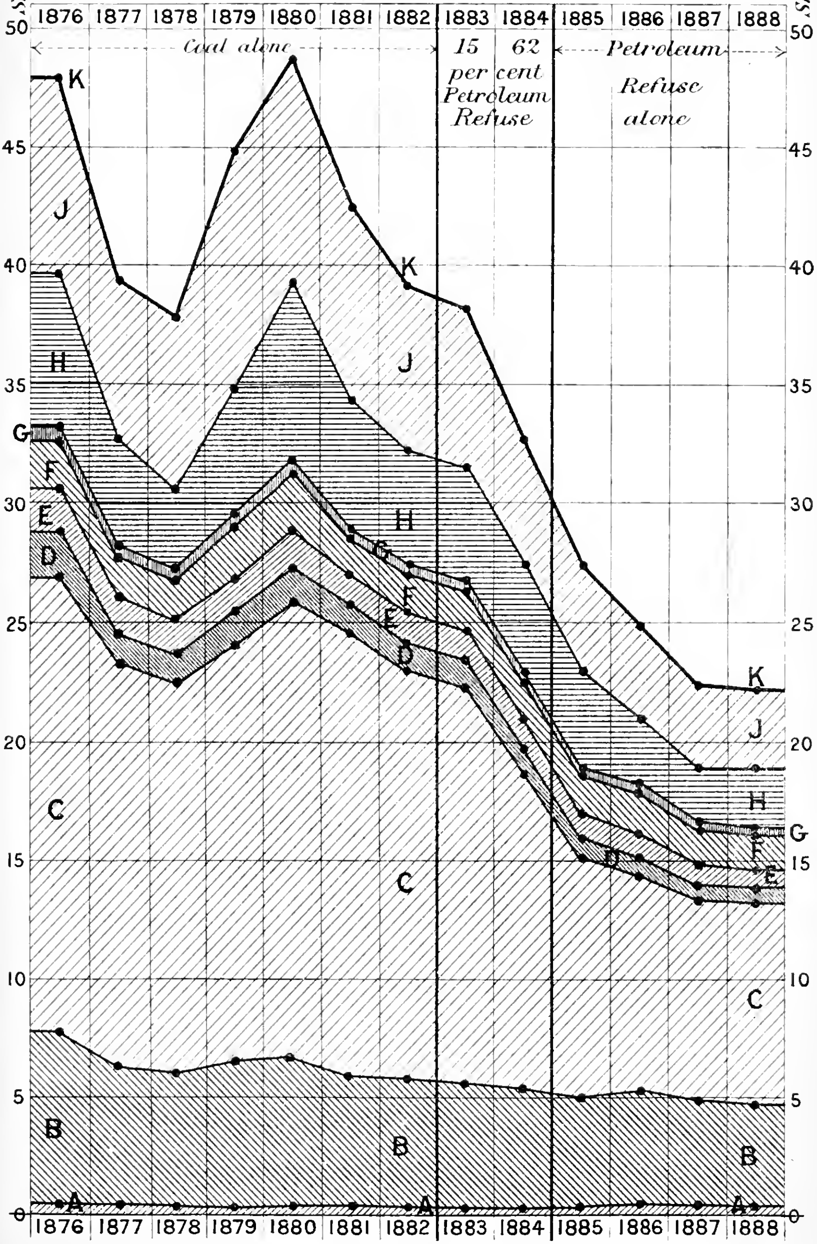


Fig. 58. *Lubrication.*

Fig. 59. *Working Cost of Locomotive Department in Shillings per 1000 Axle-miles of trucks wagons or carriages. See Table XV.*



(Mechanical Engineers 1889)

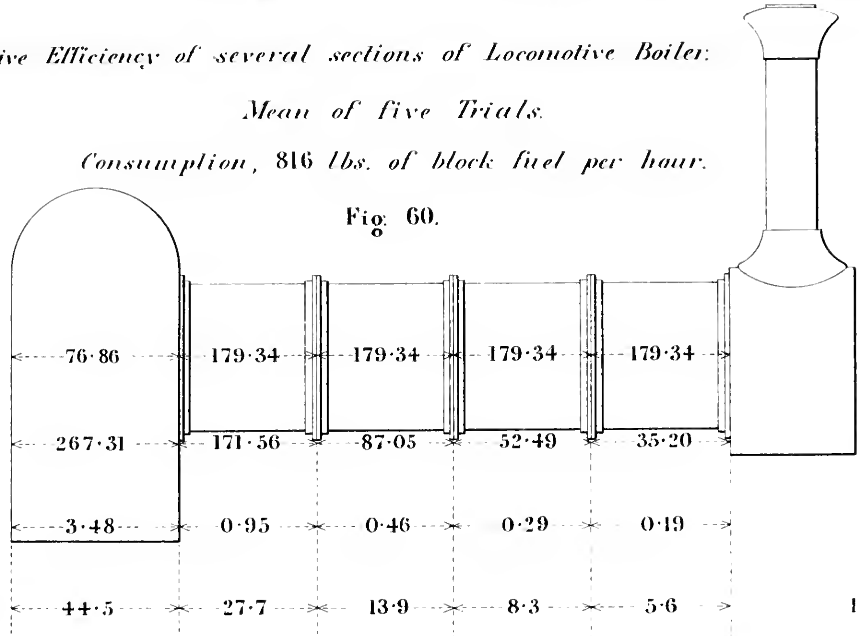
PETROLEUM FUEL IN LOCOMOTIVES.

Relative Evaporative Efficiency of several sections of Locomotive Boiler:

Mean of five Trials.

Consumption, 816 lbs. of block fuel per hour.

Fig. 60.



Heating Surface, sq. feet.	76·86	179·34	179·34	179·34	179·34	794·22 *total sq. feet.*
Evaporation, gallons.	267·31	171·56	87·05	52·49	35·20	613·80 *total gallons.*
Evaporation per sq. ft., gals.	3·48	0·95	0·46	0·29	0·19	0·78 *mean gallons.*
Relative Evaporation per cent.	44·5	27·7	13·9	8·3	5·6	100 *per cent.*

Vacuum in smoke-box in five Trials; inches of water: 0·79 1·57 2·36 3·15 3·94 *inches.*

(Mechanical Engineers 1889)

Plate 21.

LIQUID FUEL IN LOCOMOTIVES. *Plate 22.*

Liquid Fuel Injector, Great Eastern Railway.

Fig. 61. *Side Elevation.*

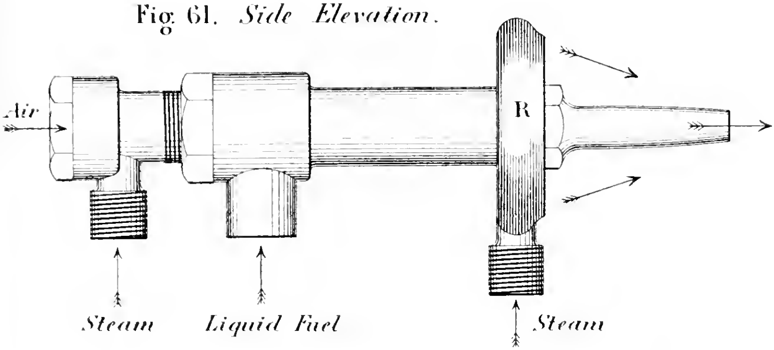


Fig. 62. *Sectional Plan of Nozzle.*

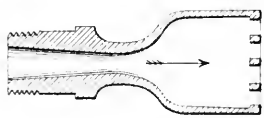


Fig. 63. *Longitudinal Section.*

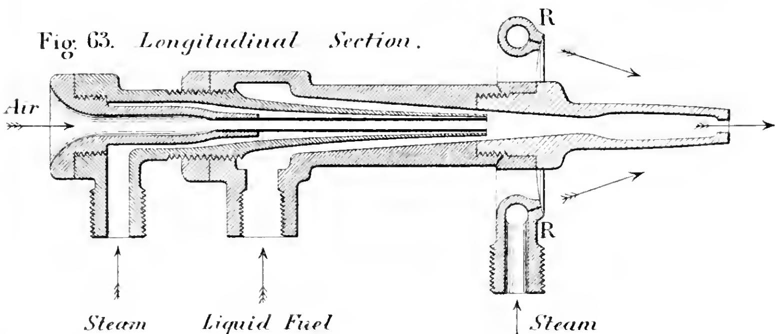


Fig. 64. *Back Elevation.*

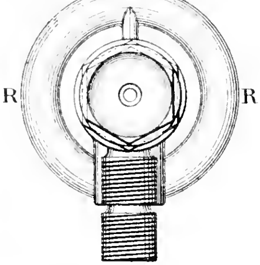
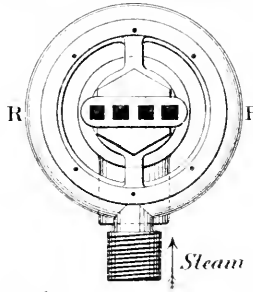


Fig. 65. *Front Elevation.*



(Mechanical Engineers 1889) *Scale 1/3rd*

COMPOUND LOCOMOTIVES.

Goods Engine, Entre Rios Government Railway. Fig. 1. *Longitudinal Section.*

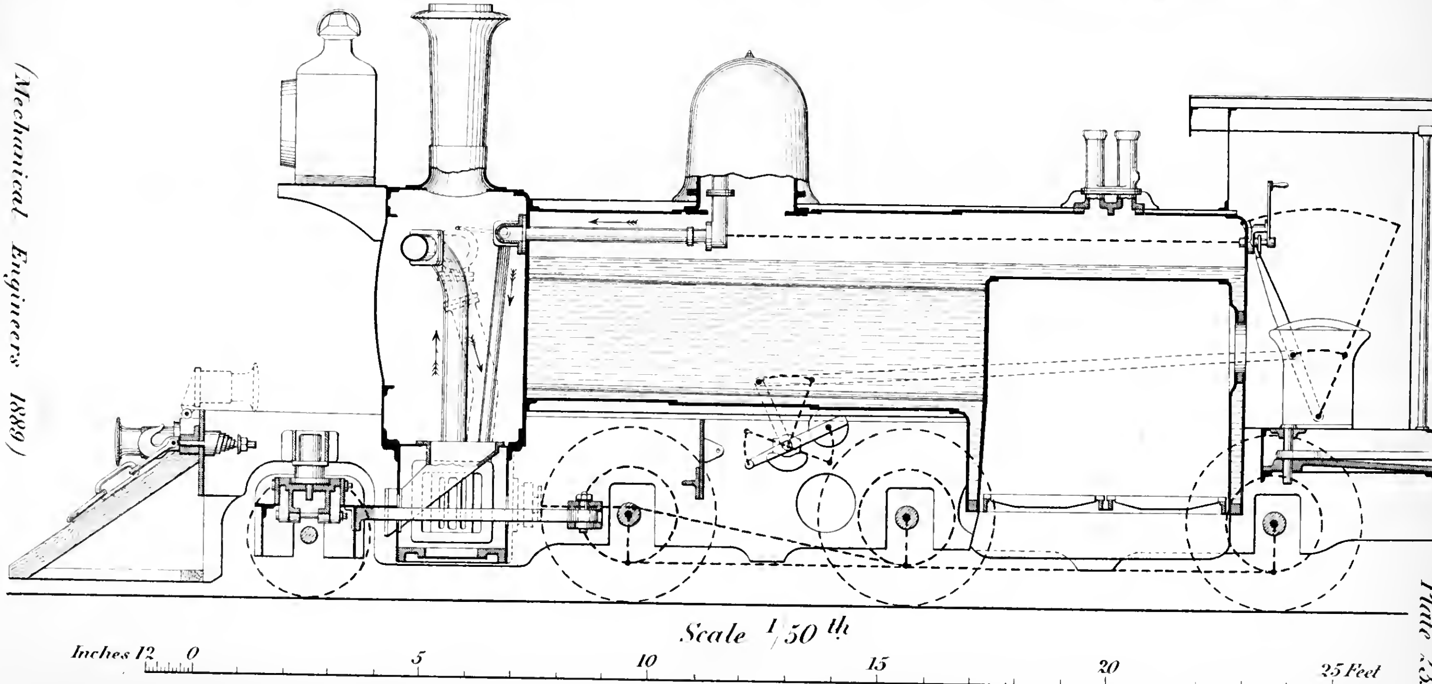


Plate 23.

COMPOUND LOCOMOTIVES. *Plate 24.*

Goods Engine, Entre Rios Government Railway.

Fig: 2. *Plan of Pipes in Smoke-box.*

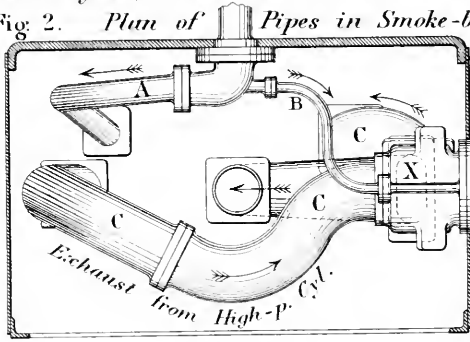
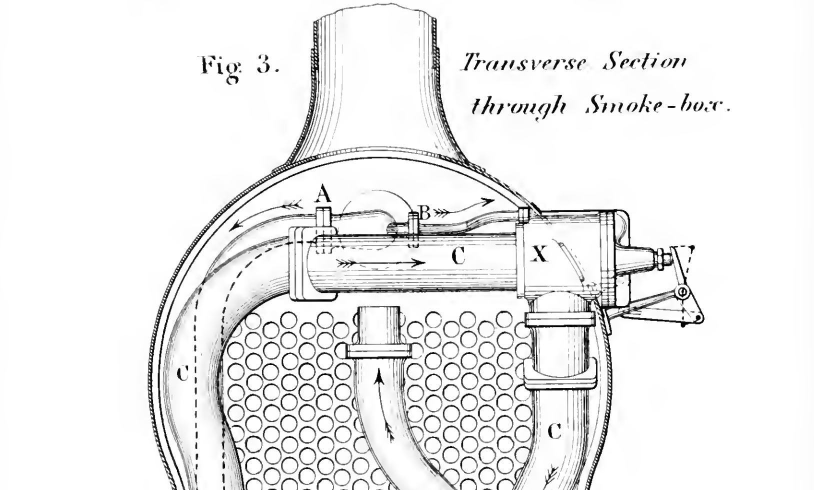


Fig: 3. *Transverse Section through Smoke-box.*



(Mechanical Engineers 1889) *Scale 1/24th*

Inches 12 6 0 1 2 3 4 5 6 Feet.

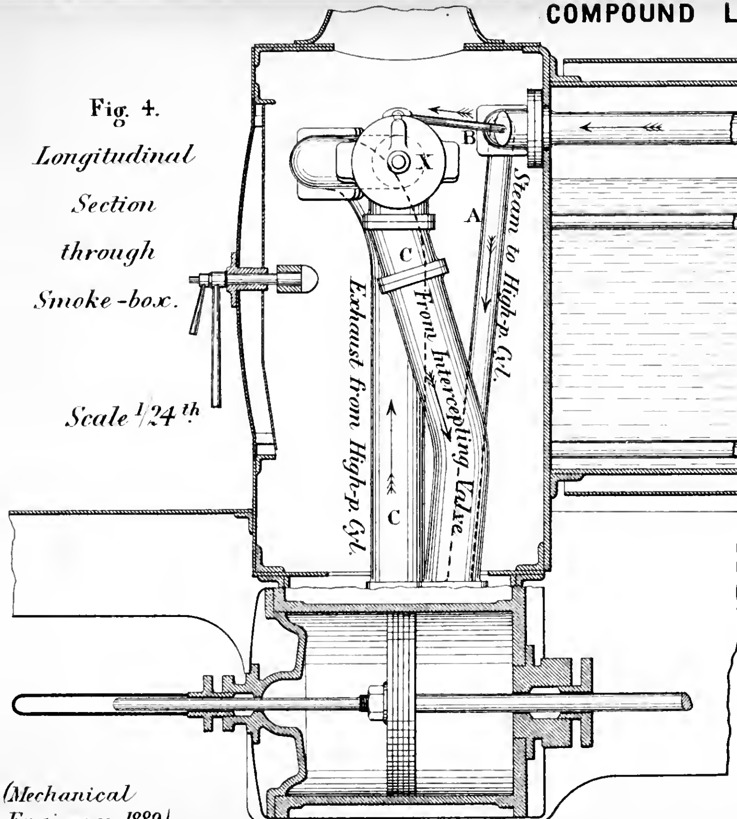


Fig. 4.
Longitudinal Section through Smoke-box.
Scale 1/24th.

Steam-ports and Slide-valves. See Tables 14, 15, and 16.

Entre-Rios Government Railway.

Fig. 5. High-Pressure.

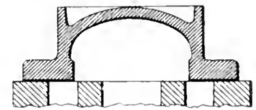
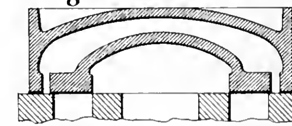


Fig. 6. Low-Pressure.



Alsace and Lorraine Railway.

Fig. 7. High-Pressure.

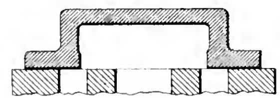
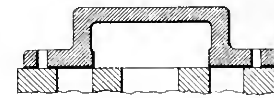


Fig. 8. Low-Pressure.



Santa Fé and Cordoba Great Southern Railway.

Fig. 9. High-Pressure.

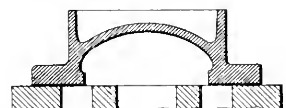
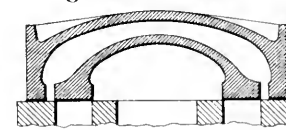


Fig. 10. Low-Pressure.



Scale 1/8th 0 5 10 15 Inches.

(Mechanical Engineers 1889)

Plate 25.

Intercepting and Starting Valves.

Scale 1/8th.

Fig. 11. *Longitudinal Section.*

Starting Valve closed, Intercepting Valve open.

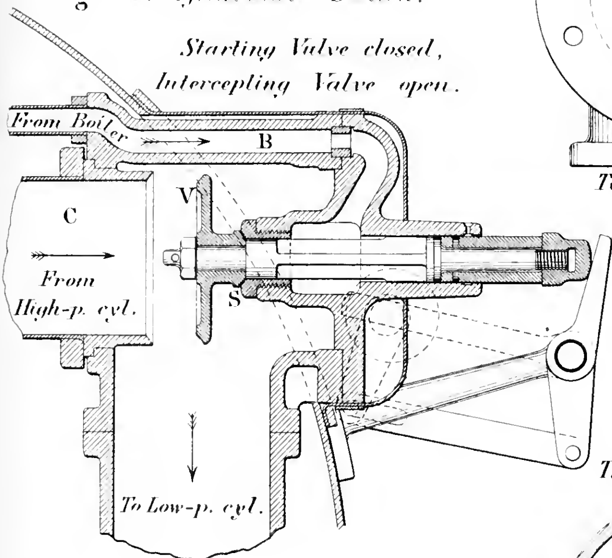


Fig. 12. *End Elevation.*

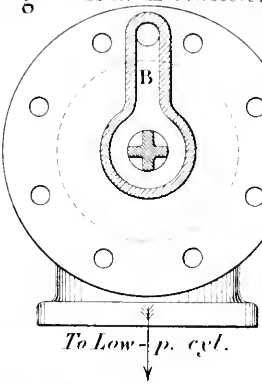


Fig. 13. *Longitudinal Section.*

Starting Valve open, Intercepting Valve closed.

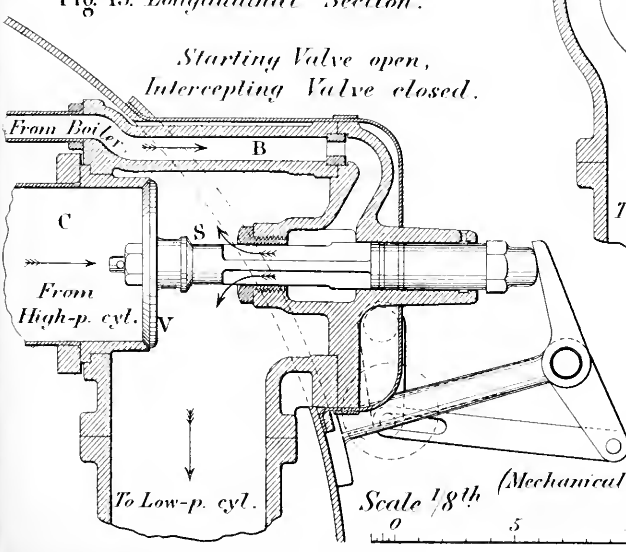
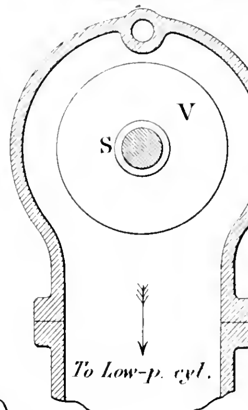


Fig. 14. *Transverse Section.*



(Mechanical Engineers 1889)

Scale 1/8th

0 5 10 15 Inches.

Modified Intercepting and Starting Valves.

End Elevation.

Fig. 15.

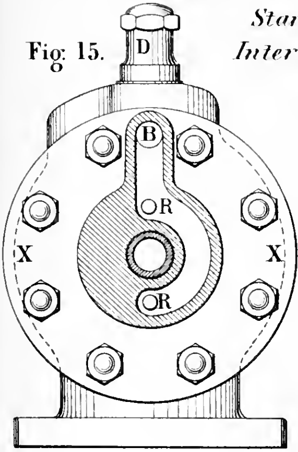


Fig. 16. *Longitudinal Section.*

Starting Valves closed, Intercepting Valve open.

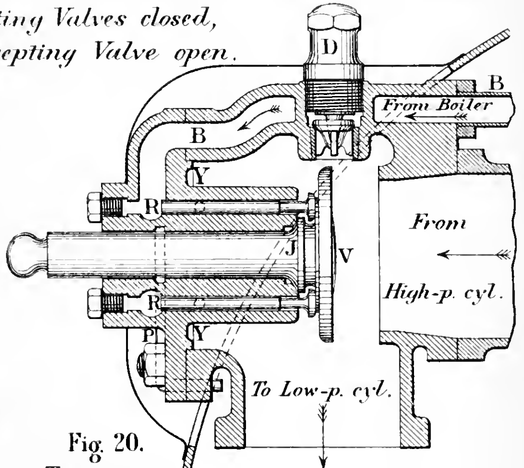


Fig. 19.
Sectional Plan at XX, Fig. 15.

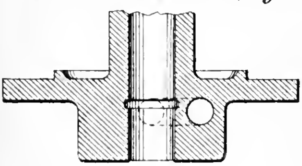
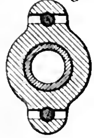


Fig. 20.
Transverse Section at YY, Fig. 16.



Sectional Plan at ZZ, Figs. 17 and 18.

Fig. 21.

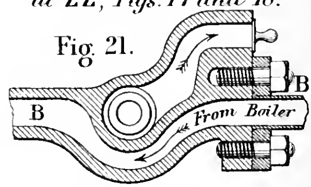


Fig. 17. *Transverse Section.*

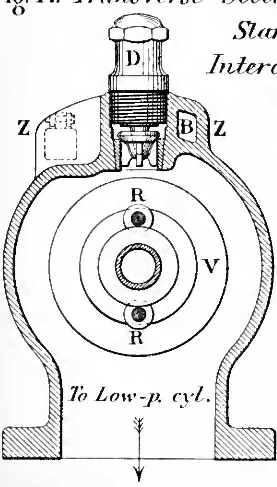
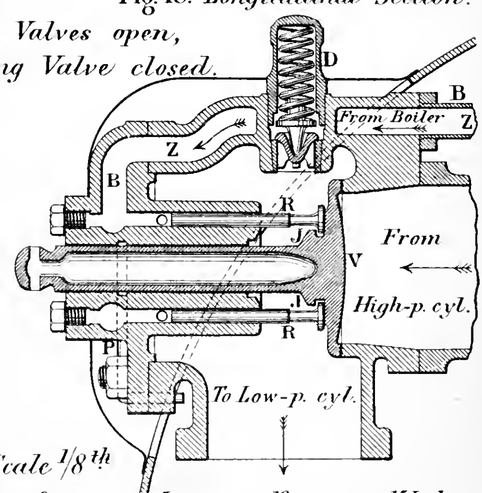


Fig. 18. *Longitudinal Section.*

Starting Valves open, Intercepting Valve closed.



Scale 1/8th

0 5 10 15 Inches.

(Mechanical Engineers 1889)

COMPOUND LOCOMOTIVES.

Valve Motion.

Plate 28.

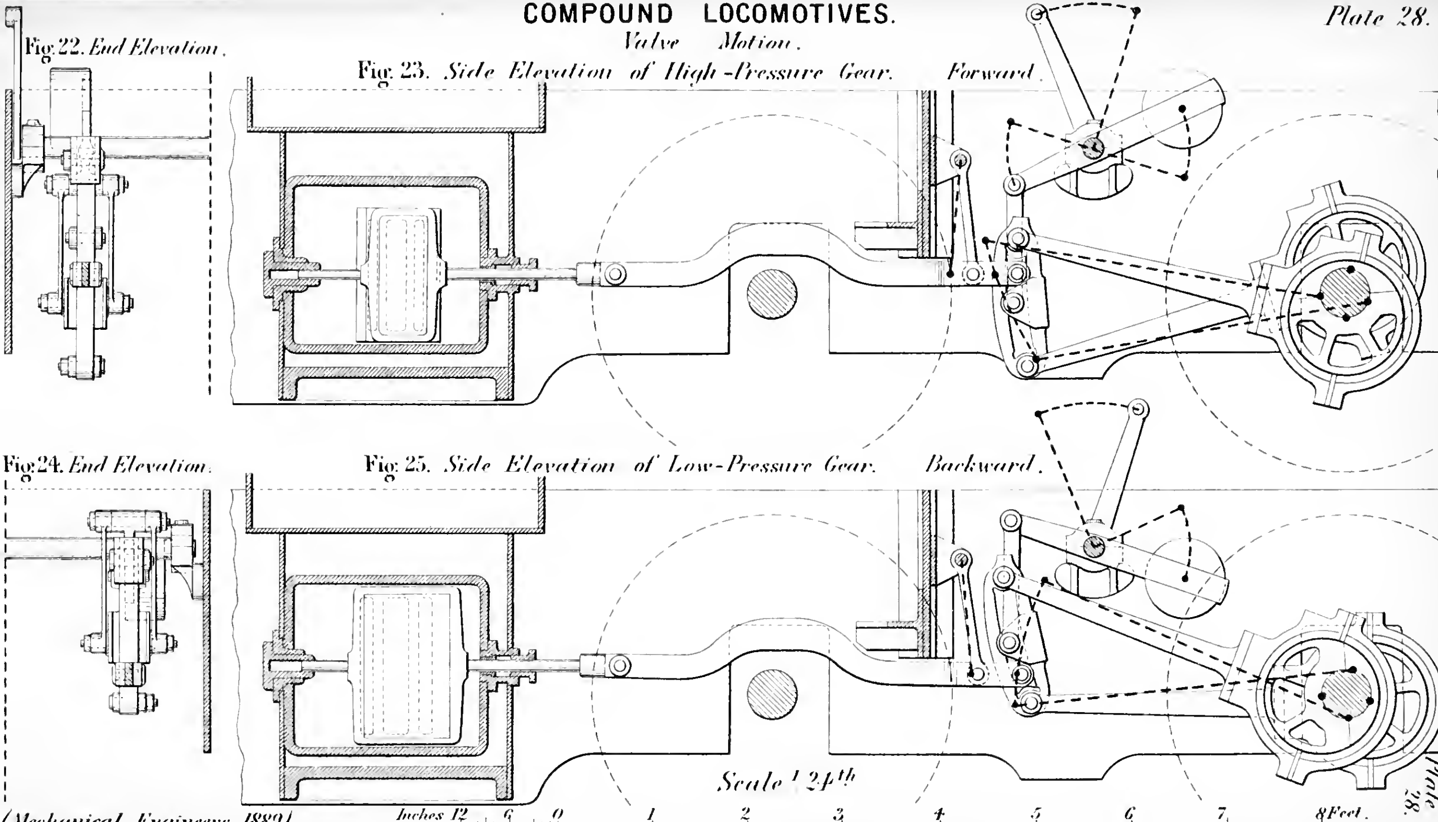


Fig. 22. *End Elevation.*

Fig. 23. *Side Elevation of High-Pressure Gear.*

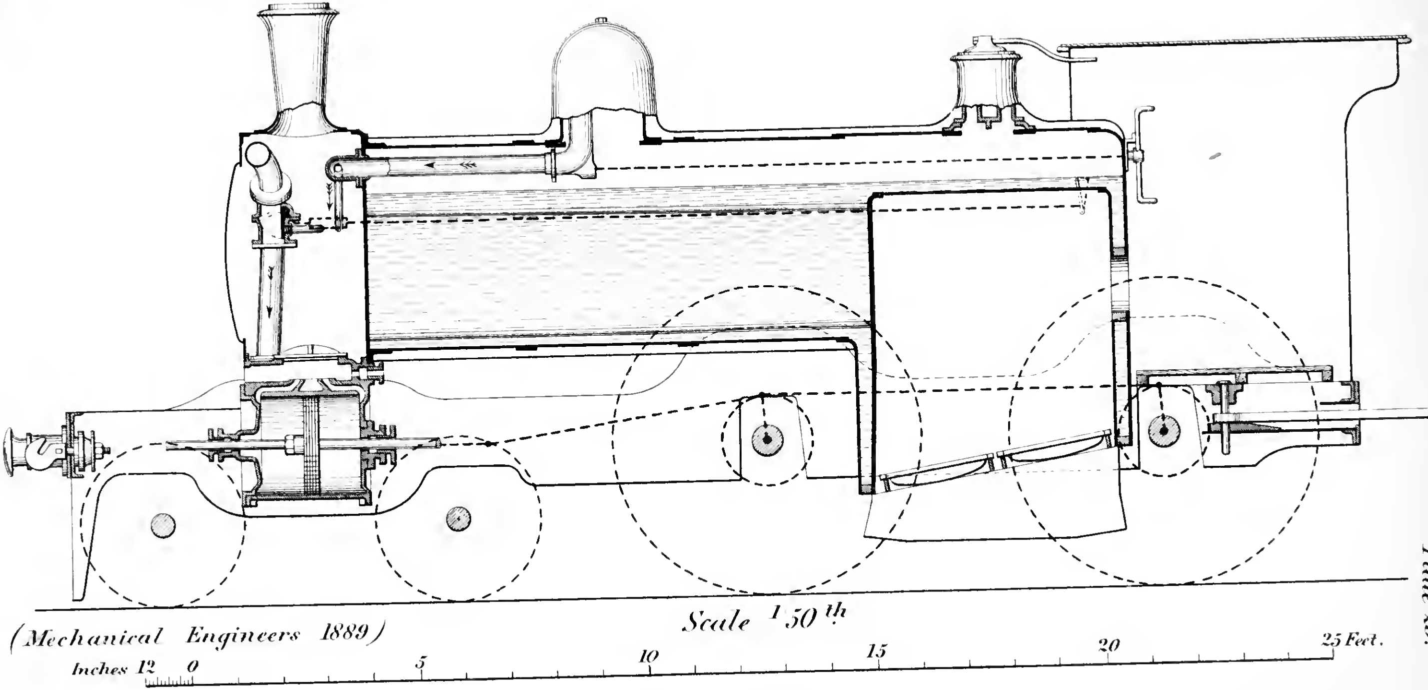
Fig. 24. *End Elevation.*

Fig. 25. *Side Elevation of Low-Pressure Gear.*

(Mechanical Engineers 1889)

COMPOUND LOCOMOTIVES.

Bogie Passenger Engine, North Eastern Railway. Fig. 26. *Longitudinal Section.*

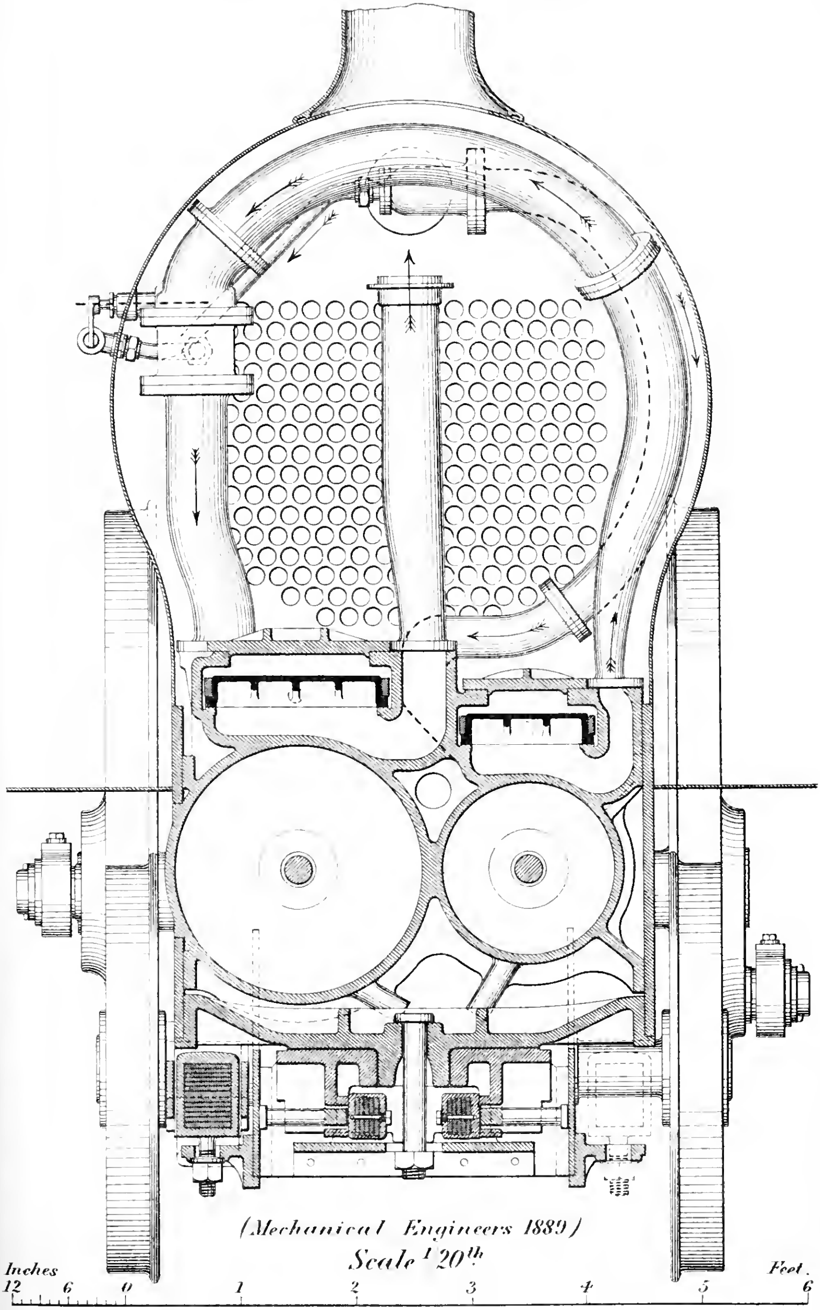


Scale 1/50th

(Mechanical Engineers 1889)

Bogie Passenger Engine, North Eastern Railway.

Fig. 27. *Transverse Section.*



(Mechanical Engineers 1889)

Scale 1/20th

COMPOUND LOCOMOTIVES. *Plate 31.*

Bogie Passenger Engine. North Eastern Railway.

Intercepting and Starting Valves.

Fig. 28. *Side Elevation.*

Intercepting Valve closed, Starting Valve open.

Scale 1/8th.

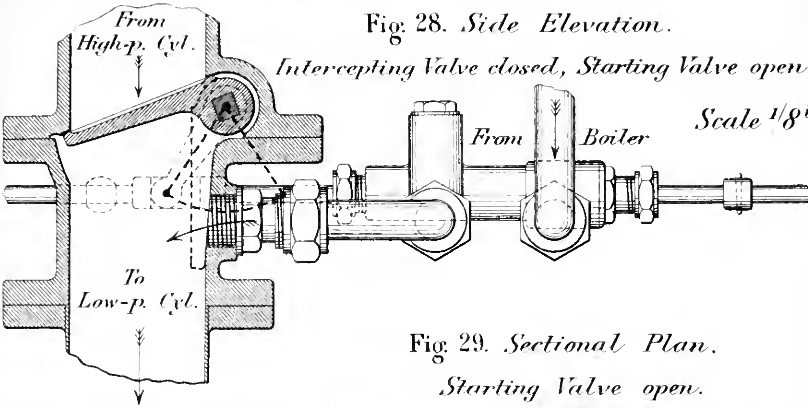
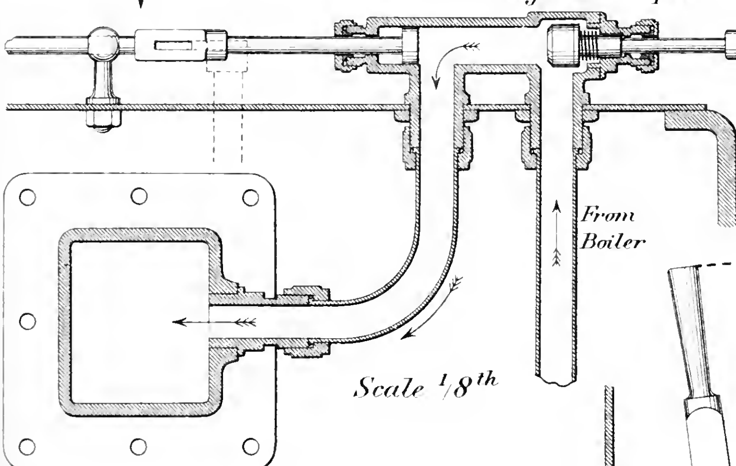


Fig. 29. *Sectional Plan.*

Starting Valve open.



Scale 1/8th

Fig. 30. *Starting Valve closed.* *Scale 1/4th.*

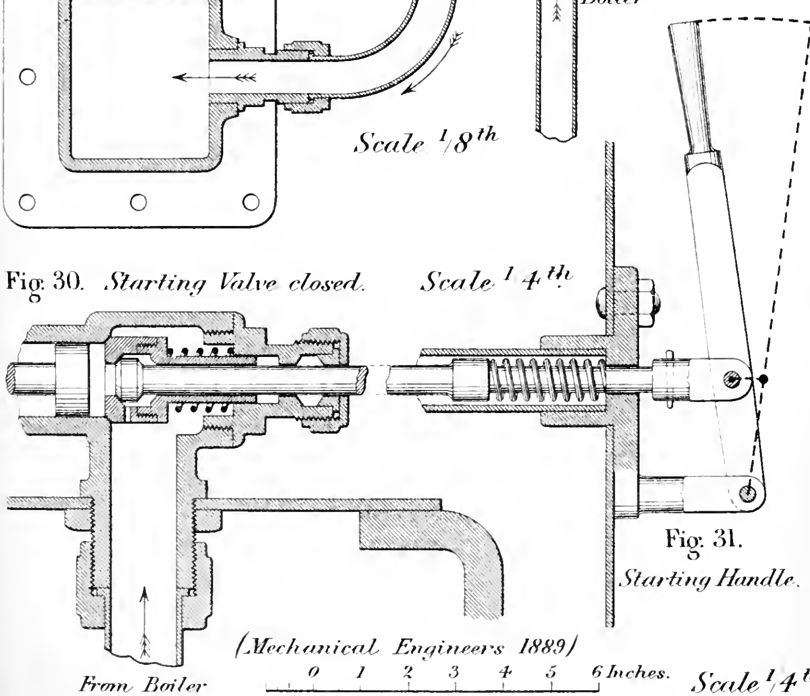


Fig. 31. *Starting Handle.*

(Mechanical Engineers 1889)

0 1 2 3 4 5 6 Inches. *Scale 1/4th.*

COMPOUND LOCOMOTIVES.

Passenger Engine, Santa Fé & Cordoba Great Southern Railway.

Smoke-box end.

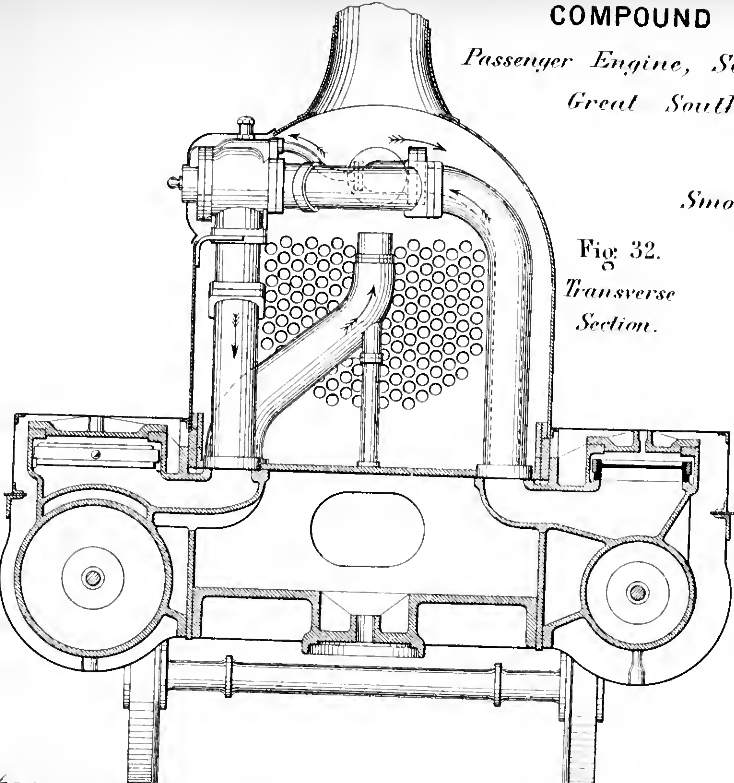


Fig. 32. *Transverse Section.*

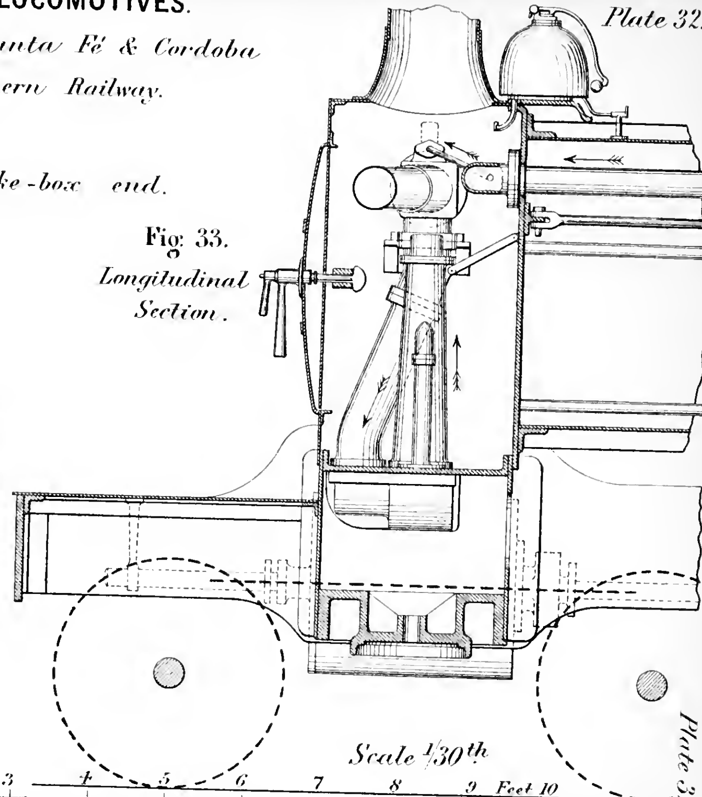


Fig. 33. *Longitudinal Section.*

Scale 1/30th.

Inches 12 6 0 1 2 3 4 5 6 7 8 9 Feet 10

Plate 32.

Passenger Express Engine, North Eastern Railway.

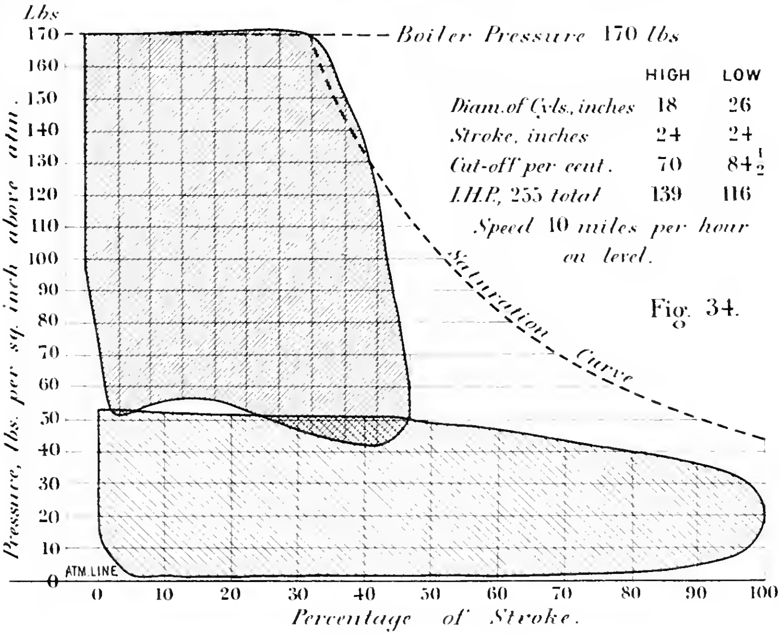


Fig. 34.

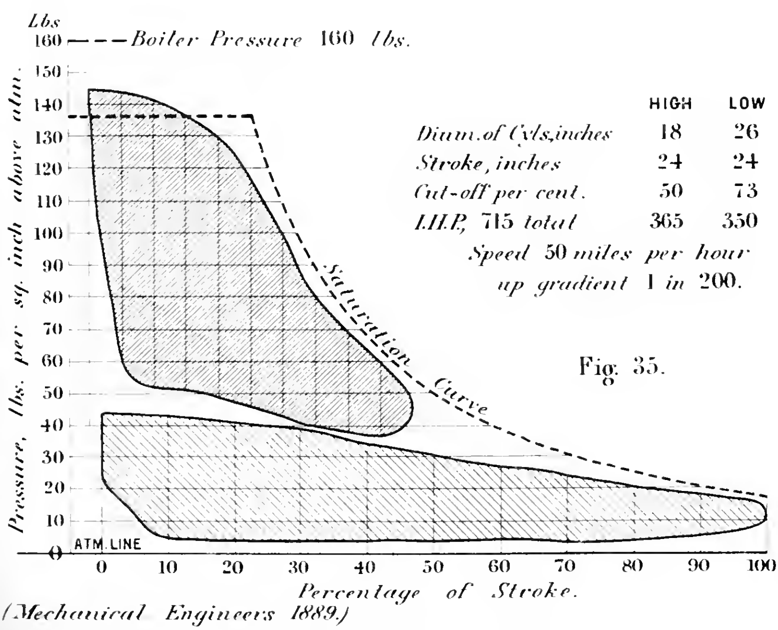


Fig. 35.

(Mechanical Engineers 1889.)

Goods Engine, North Eastern Railway.

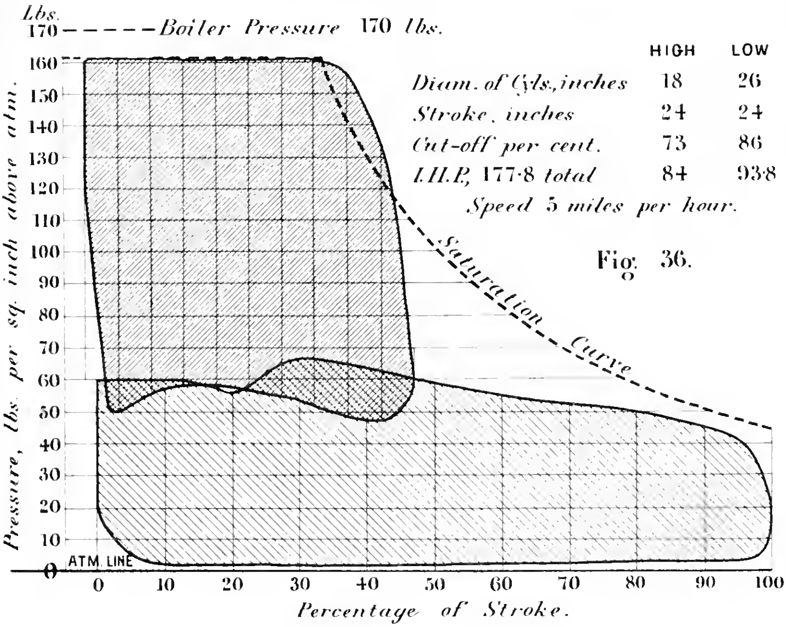


Fig. 36.

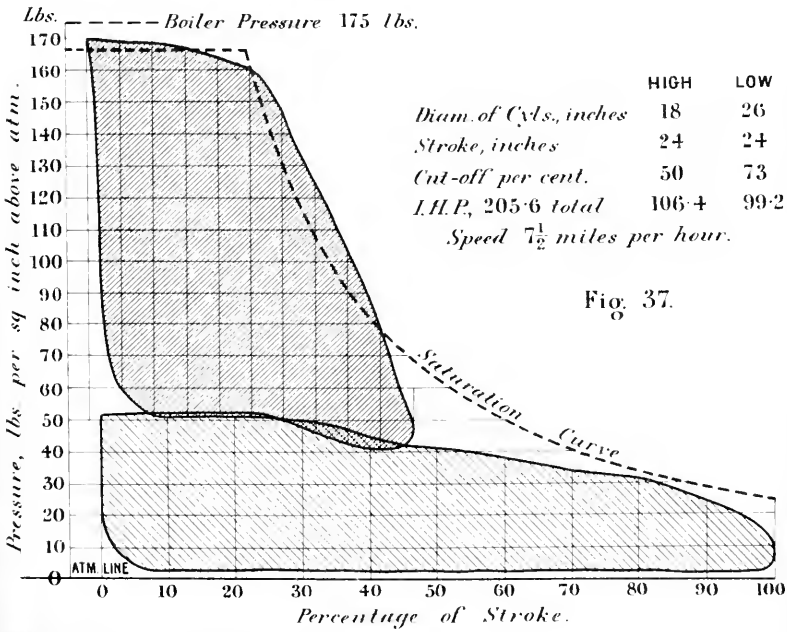


Fig. 37.

(Mechanical Engineers 1889)

Hannover State Railways. Fig. 38. *Passenger Engine.*

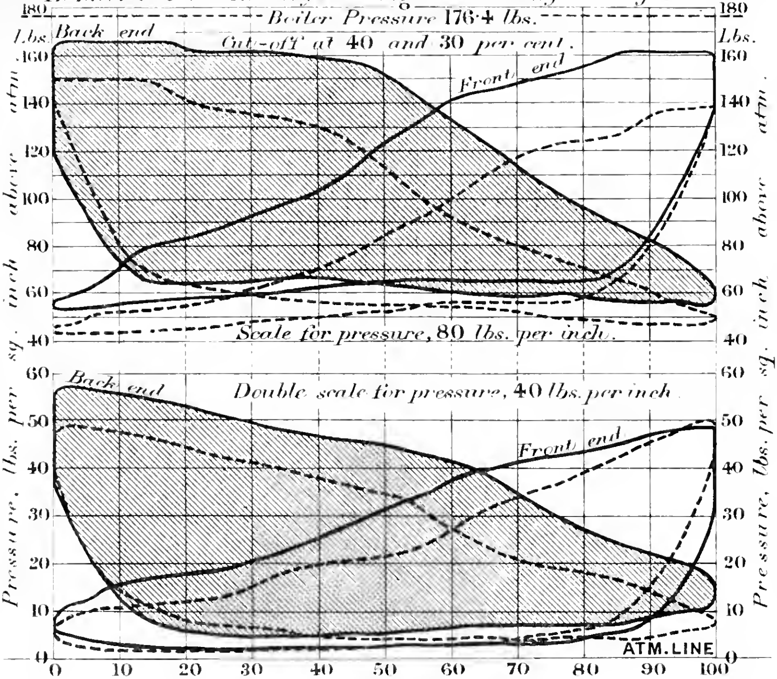
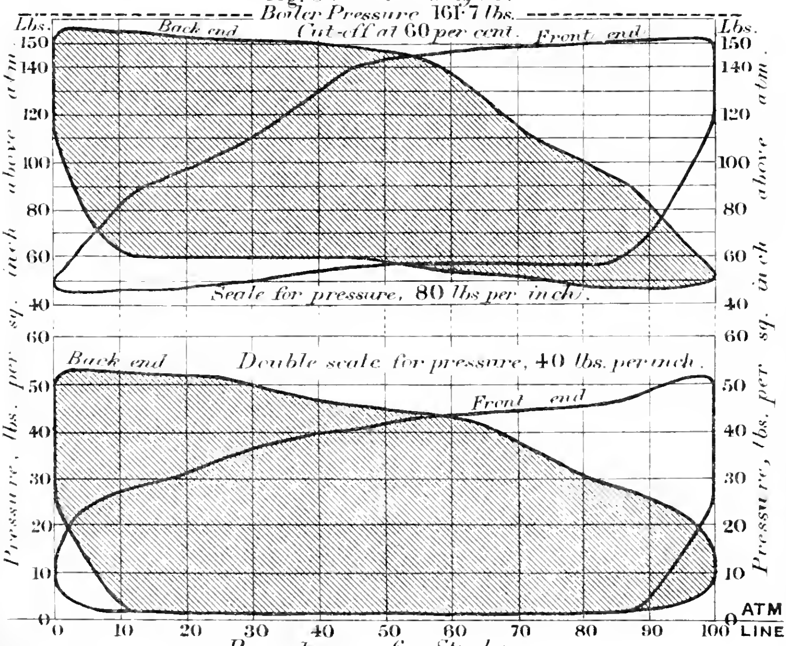


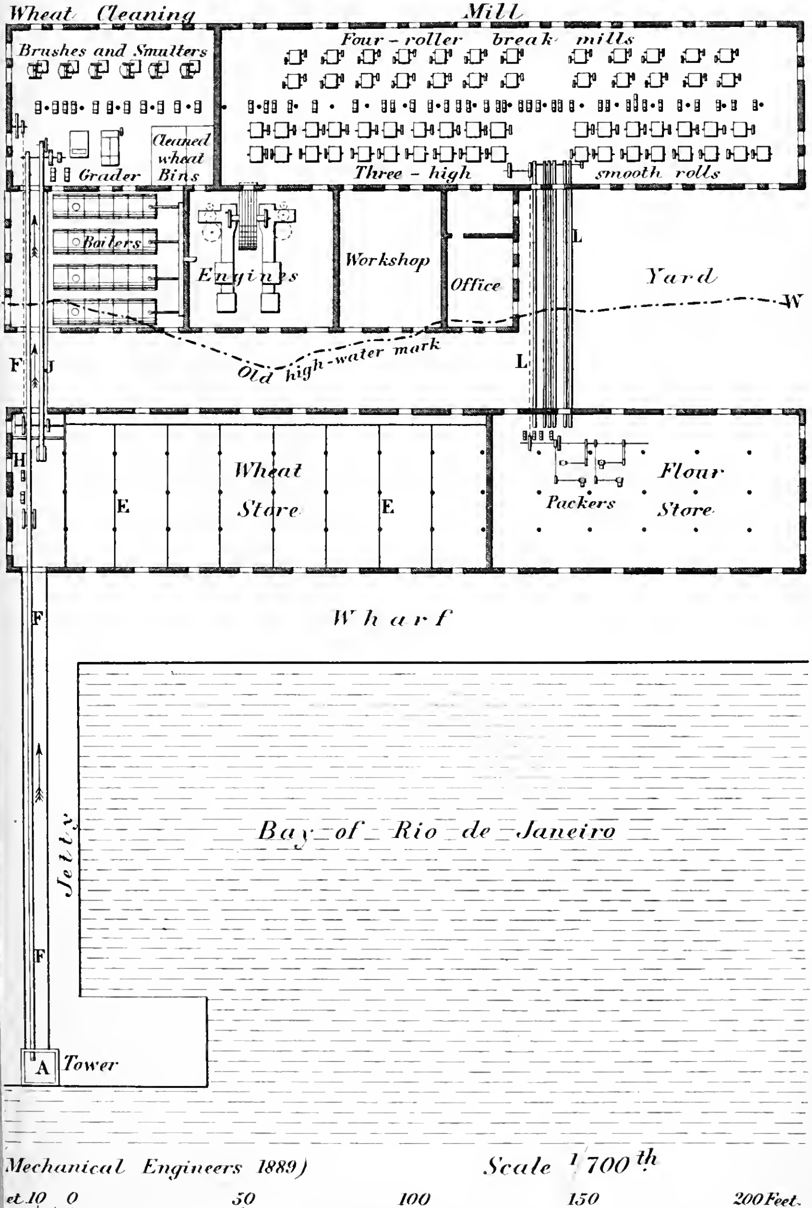
Fig. 39. *Goods Engine.*



(Mechanical Engineers 1889)

Roller Flour Mill and Granary at Rio de Janeiro.

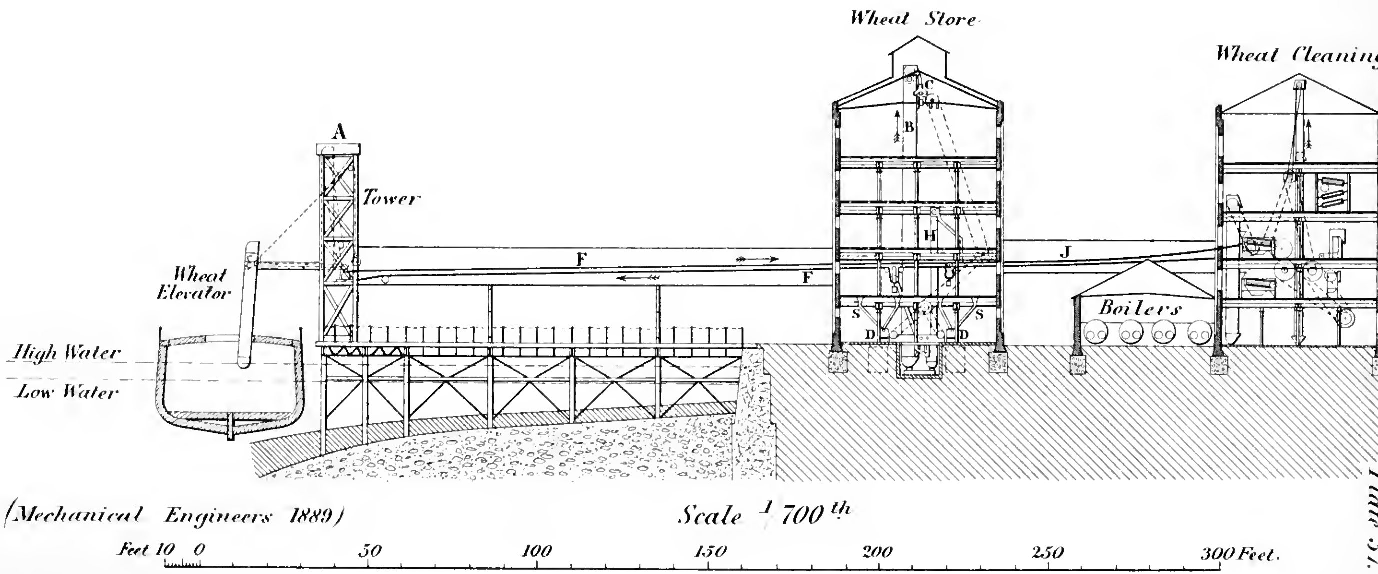
Fig. 1. *Plan.*



ROLLER FLOUR MILLING.

Roller Flour Mill and Granary at Rio de Janeiro.

Fig. 2. *Transverse Section.*



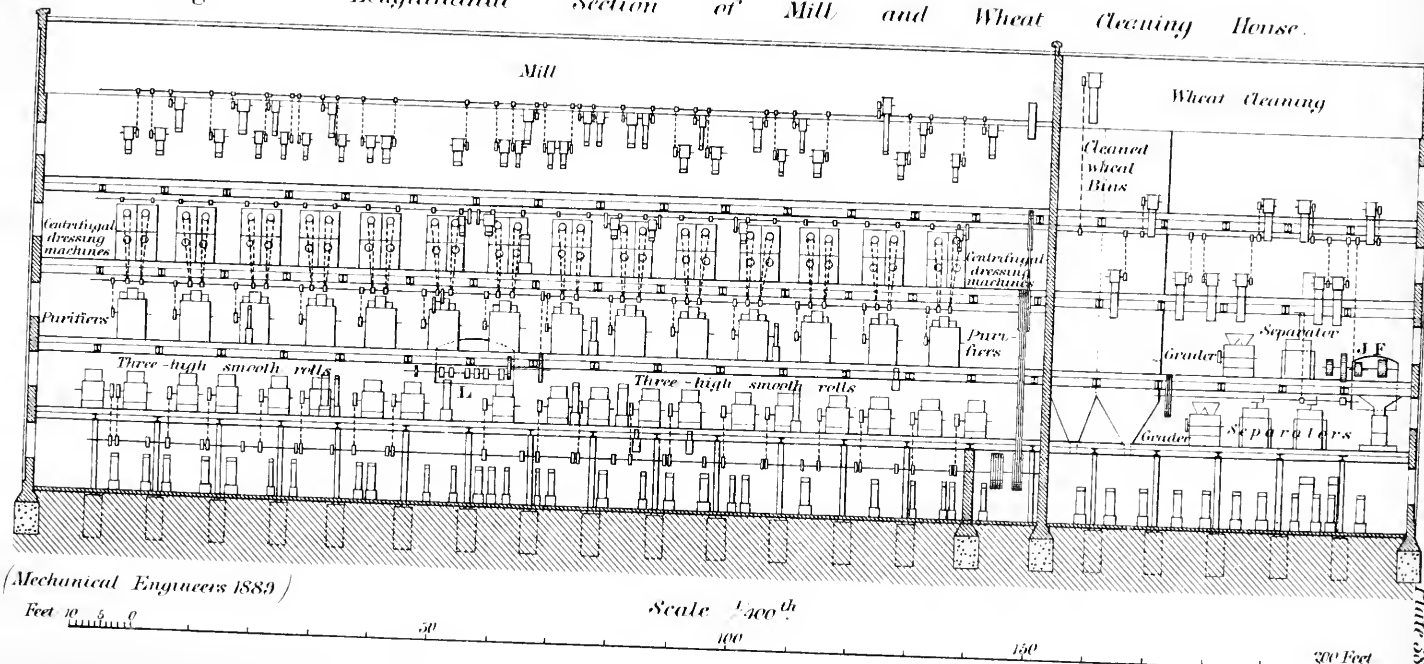
(Mechanical Engineers 1889)

Plate 37.

ROLLER FLOUR MILLING.

Roller Flour Mill and Granary at Rio de Janeiro

Fig. 3. Longitudinal Section of Mill and Wheat Cleaning House.



(Mechanical Engineers 1889)

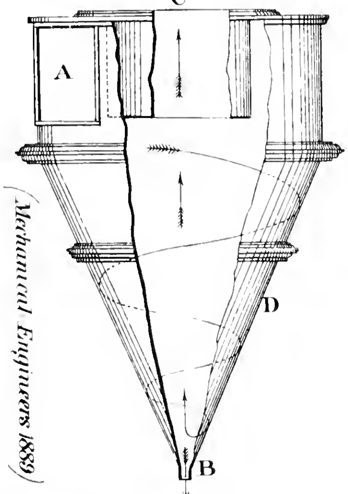
Scale 1/400th

ROLLER FLOUR MILLING.

Dust Collector.

Scale 1/10th

Fig. 5. Sectional Elevation.



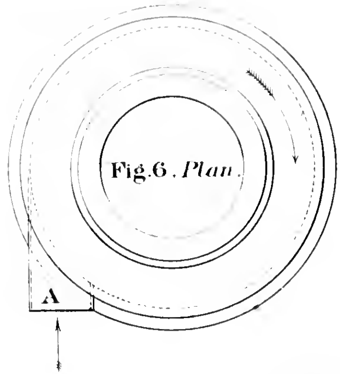
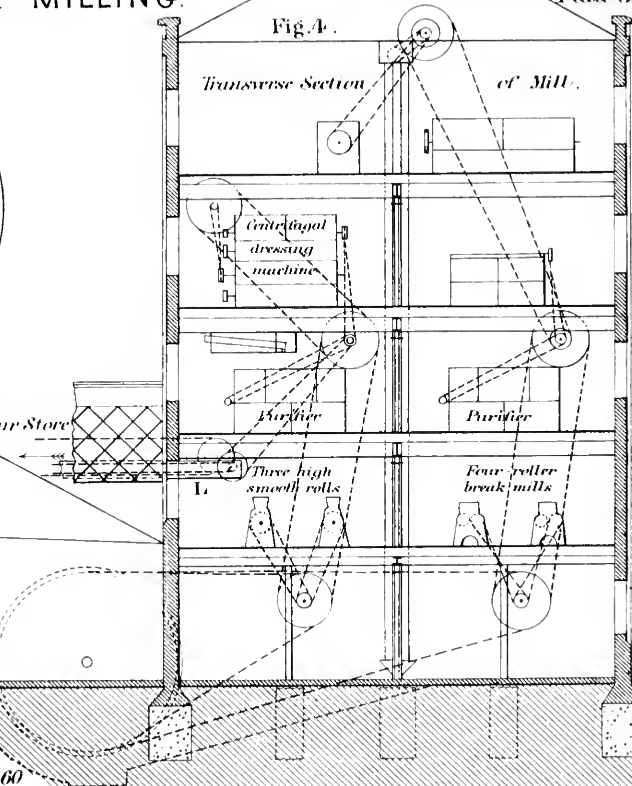


Fig. 4.



Scale 1/240th

Feet 10 5 0 10 20 30 40 50 Feet 60

(Mechanical Engineers 1889)

Plate 39.

ROLLER FLOUR MILLING.

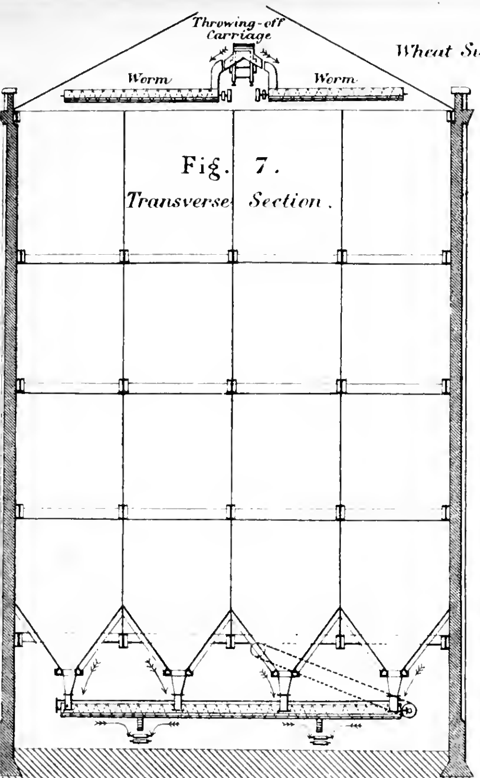


Fig. 7. Transverse Section.

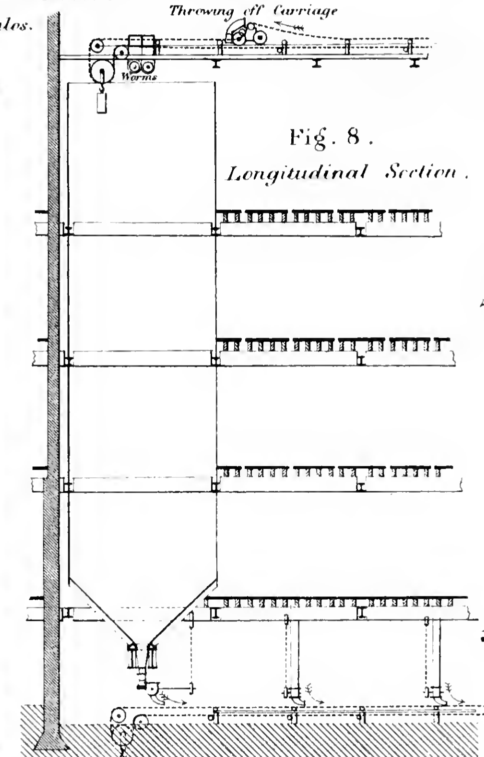


Fig. 8. Longitudinal Section.

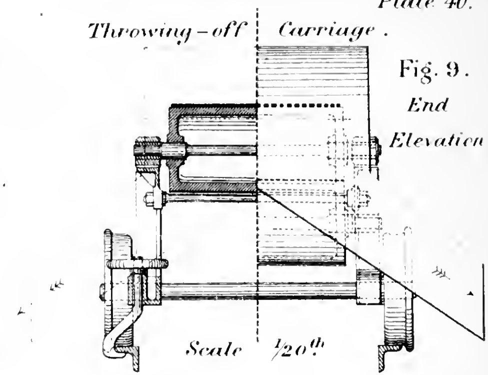


Fig. 9. End Elevation.

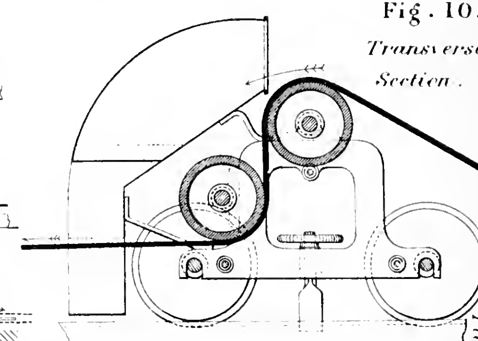


Fig. 10. Transverse Section.

Scale 1/240th. 10 Feet 0 10 20 30 40 50 60 Feet 70

Plate 40.

Fig. 11. *Four-Roller Mill.*

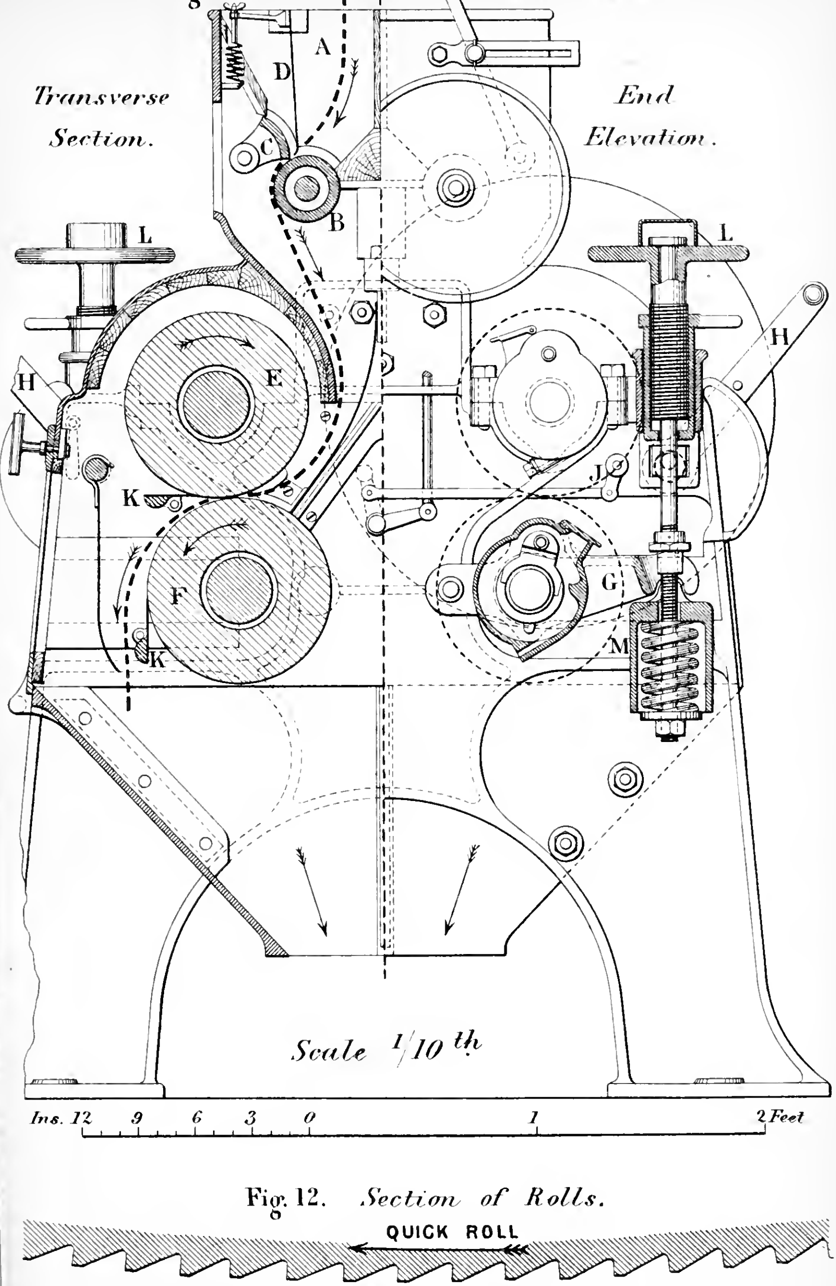
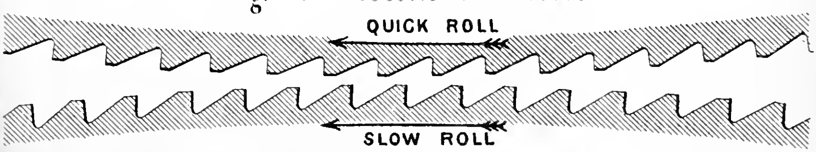


Fig. 12. *Section of Rolls.*

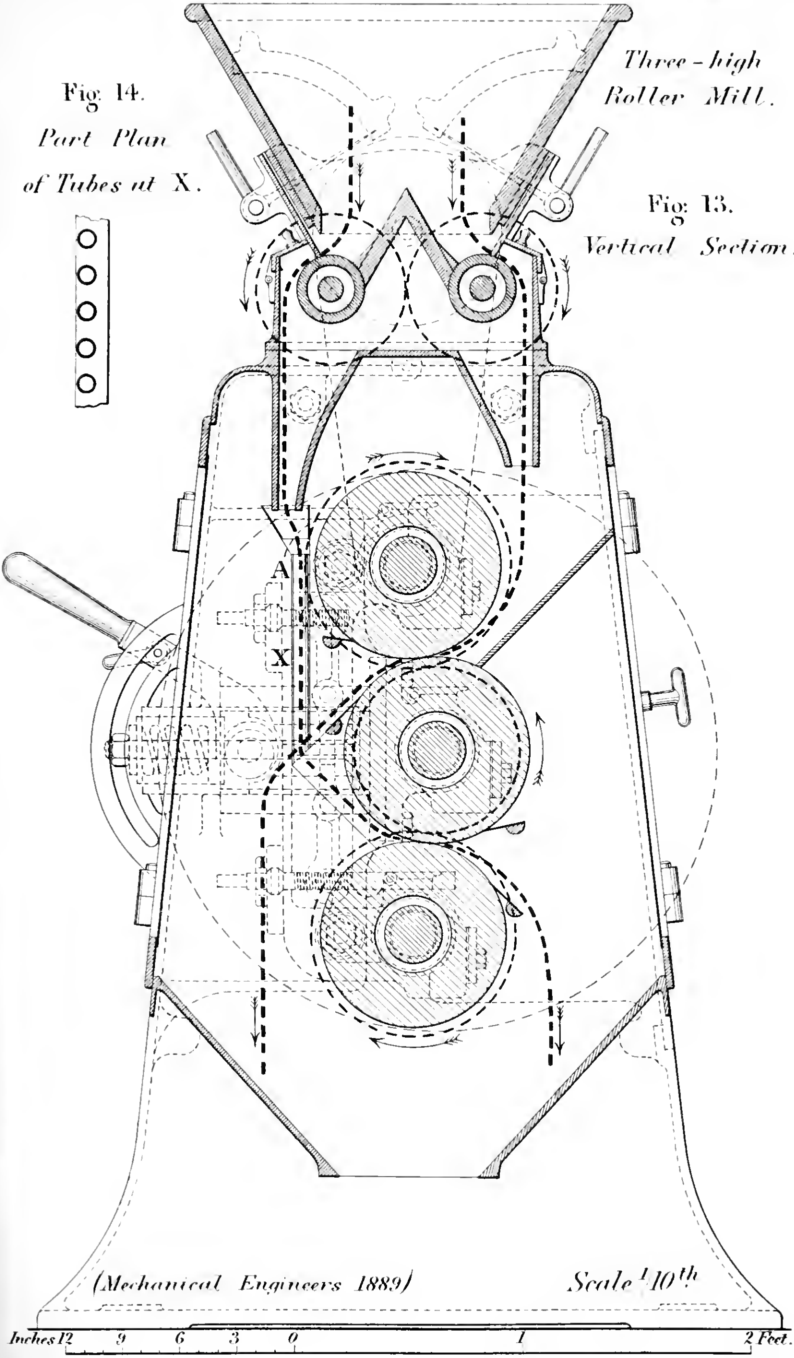


(Mechanical Engineers 1889) *Scale 4 times full size.*

Fig. 14.
Part Plan of Tubes at X.

Three-high Roller Mill.

Fig. 13.
Vertical Section.

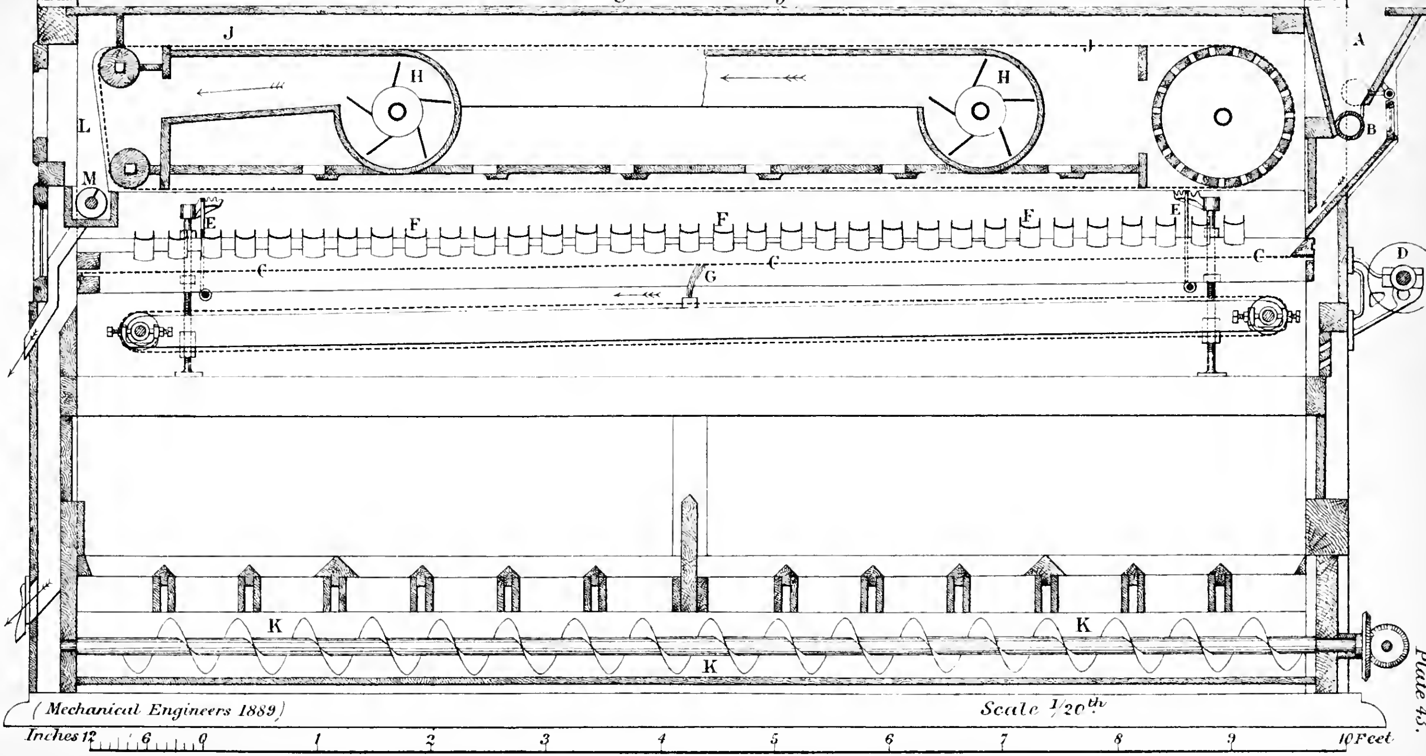


(Mechanical Engineers 1889)

Scale 1/10th

ROLLER FLOUR MILLING.

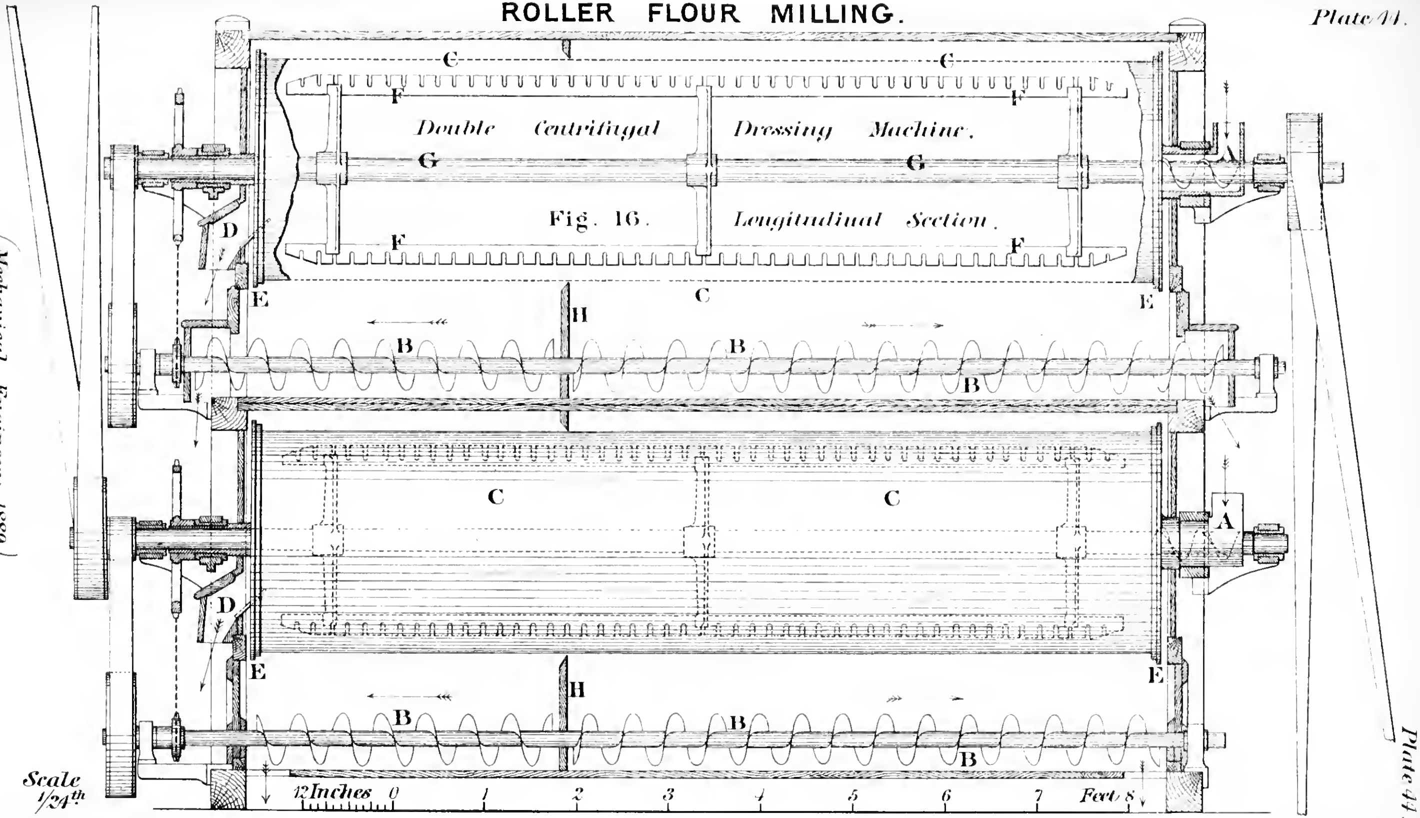
Purifier. Fig. 13. Longitudinal Section.



(Mechanical Engineers 1889)

Scale 1/20th.

ROLLER FLOUR MILLING.



(Mechanical Engineers 1889)

14

Institution of Mechanical Engineers.

PROCEEDINGS.

May 1889.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 1st May 1889, at Half-past Seven o'clock p.m.; Charles Cochrane, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced the decease of Mr. Richard Peacock, M.P., Vice-President, one of the few original Members who met together in 1846 and joined in establishing the Institution on 27th January 1847. A letter of condolence had been sent to his family from the Council. The vacancy so created in the Council had been filled up by the Council by the appointment of Sir James Ramsden as a Vice-President, and of Dr. John Hopkinson as a Member of Council.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-four candidates were found to be duly elected:—

MEMBERS.

Isaac Bradley,	Birmingham.
Charles Briggs, Jun.,	Pernambuco.
Thomas Alexander Clark,	Edinburgh.
Ernest Richard Dolby,	London.
Richard Oliver Gardner Drummond,	Kimberley.

HERBERT ANDERTON FOSTER, . .	Bradford.
FREDERICK HENRY GILL, . . .	London.
WILLIAM TOM GOOLD, . . .	London.
ARTHUR RIPLEY HILL, . . .	Leeds.
CONRAD KNAP, ...	London.
JAMES ALEXANDER MACDONALD, . .	Chesterfield.
THOMAS NASH, ...	Sheffield.
JOHN BENNETT PRICE, ...	Preston.
JAMES THOMAS RATCLIFFE, . . .	Lodz.
JAMES HERMANN ROSENTHAL, . .	London.

ASSOCIATES.

JOHN BARR, ...	Kilmarnock.
WILLIAM MCKINNEL, ...	Sheffield.

GRADUATES.

ARTHUR ROBERT MACLEAN BARROW, .	Brighton.
JOHN STUART ELLIS, ...	London.
THOMAS WATKIN HOSGOOD, . . .	Swansea.
BASIL HUMBERT JOY, ...	London.
HENRY BUCKLEY BINGHAM SMITH, . .	Glasgow.
EDWARD TURNLEY WILLIS, . . .	Glasgow.
RICHARD ERNEST WINKFIELD, . .	Swindon.

The PRESIDENT then delivered his inaugural Address: after which the following Paper was read and partly discussed :—

Research Committee on Marine-Engine Trials: Report upon Trials of the s.s. "Meteor"; by Professor ALEXANDER B. W. KENNEDY, F.R.S., Chairman.

At a Quarter before Ten o'clock the Discussion was adjourned till the following evening. The attendance was 82 Members and 46 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Thursday, 2nd May 1889, at Half-past Seven o'clock p.m.; Charles Cochrane, Esq., President, in the chair.

The Discussion upon the Report on Marine-Engine Trials was resumed, and continued until shortly after Ten o'clock, when it was again adjourned till the following afternoon. The attendance was 58 Members and 44 Visitors.

The Adjourned Meeting was held at the Institution of Civil Engineers, London, on Friday, 3rd May 1889, at Half-past Two o'clock p.m.; Charles Cochrane, Esq., President, in the chair.

The Discussion upon the Report on Marine-Engine Trials was continued and concluded. The following Paper was then read and discussed:—

Description of an Apparatus for Drying in Vacuum; by Mr. Emil Passburg, of Breslau. Communicated through Mr. Samuel Geoghegan, of Dublin.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated, shortly after Half-past Four o'clock. The attendance was 43 Members and 30 Visitors.

In the evening the Annual Dinner of the Institution was held at The Criterion, Piccadilly, and was largely attended by the Members and their friends. The President occupied the chair, and the following Guests accepted the invitations sent to them, though some were unavoidably prevented at the last from being present.

The Right Honourable the Earl of Crawford and Balcarres, F.R.S., Honorary Life Member; Captain Lord Charles Beresford, R.N., C.B., M.P.; Sir Frederick A. Abel, C.B., F.R.S., Honorary Life Member; Sir George Elliot, Bart., M.P.; Mr. William Mather, M.P.

Institution of Civil Engineers.—Sir George B. Bruce, President. Sir John Fowler, K.C.M.G.; Mr. Thomas Hawksley, F.R.S.; Mr. James Abernethy, F.R.S.E.; Past-Presidents. Mr. George Berkley; Mr. Harrison Hayter; Mr. Alfred Giles, M.P.; Vice-Presidents. Mr. Benjamin Baker; Mr. Charles Hawksley; Mr. James Mansergh; Sir Robert Rawlinson, K.C.B.; Sir Edward James Reed, K.C.B., F.R.S., M.P.; Mr. William Shelford; Members of Council. Mr William Pole, F.R.SS. L. and E., Honorary Secretary. Mr. James Forrest, Secretary.

Professor G. G. Stokes, M.P., F.R.S., President of the Royal Society; Mr. John Marley, President of the North of England Institute of Mining and Mechanical Engineers; Mr. Edward P. Martin, President of the South Wales Institute of Engineers; Mr. Elias P. Squarey, President of the Surveyors' Institution; Mr. Daniel Adamson, President of the Iron and Steel Institute; Mr. Francis C. Marshall, President of the North-East Coast Institution of Engineers and Shipbuilders.

Mr. Thomas Aitken, Manager, London and Edinburgh Shipping Co.; Mr. Henry Cochrane; Mr. Henry Heath Cochrane; Mr. John Cochrane; Professor James H. Cotterill, F.R.S.; Mr. Joseph Gordon, Borough Surveyor, Leicester; Mr. Henry Lambert, General Manager, Great Western Railway; Mr. Robert A. McLean, Auditor; Mr. Harry Lee Millar, Treasurer; Mr. Henry Brinsley Sheridan; Mr. W. Strohn, Breslau; Mr. Archibald Thomson; Mr. Ralph H. Tweddell; Mr. Gustav Weitzmann; Mr. Charles J. Wilson, F.C.S.

The President was supported by the following Officers of the Institution, some of whose names have already been recorded in another capacity:—Sir Lowthian Bell, Bart., F.R.S., Mr. Edward H. Carbutt, Mr. Thomas Hawksley, F.R.S., Mr. Jeremiah Head, Past-Presidents; Mr. Daniel Adamson, Sir James N. Douglass, F.R.S., Mr. Arthur Paget, Mr. Joseph Tomlinson, Vice-Presidents;

Sir Douglas Galton, K.C.B., D.C.L., F.R.S., Professor Alexander B W. Kennedy, F.R.S., Mr. John G. Mair, Mr. Henry D. Marshall, Mr. Edward B. Marten, Mr. Edward P. Martin, Mr. E. Windsor Richards, Members of Council.

After the usual loyal toasts had been proposed by the President, the toast of "The Houses of Parliament" was proposed by Mr. Edward H. Carbutt, Past-President, and acknowledged on behalf of the House of Lords by the Right Honourable the Earl of Crawford and Balcarres, F.R.S., Honorary Life Member, and for the House of Commons by Mr. Alfred Giles, M.P. Mr. Daniel Adamson, Vice-President, proposed "The Army and Navy"; and in responding on behalf of both services and for the reserve forces of each, Captain Lord Charles Beresford, R.N., C.B., M.P., indicated the reforms and improvements he considered desirable to be carried out in the interests of the British Empire. The toast of "The Learned Societies," proposed by Mr. Joseph Tomlinson, Vice-President, was acknowledged by Professor G. G. Stokes, M.P., F.R.S., President of the Royal Society. The toast of "The Professional Institutions," proposed by Mr. Arthur Paget, Vice-President, was acknowledged by Sir George B. Bruce, President of the Institution of Civil Engineers, and Mr. Francis C. Marshall, President of the North-East Coast Institution of Engineers and Shipbuilders. The concluding toast of "The Institution of Mechanical Engineers," proposed by Sir John Fowler, K.C.M.G., Past-President of the Institution of Civil Engineers, was acknowledged by the President.

ADDRESS BY THE PRESIDENT,

CHARLES COCHRANE, ESQ.

I have found great difficulty in deciding to present the Members of this Institution with an Address on the occasion of my election to the Presidency, feeling that the practice of doing so might be more honoured in this instance in its breach than in its observance; but being reminded I had the world to roam over, and that whatever I might say would not be debatable, I have ventured on an attempt to follow the usual custom. The difficulty consists in knowing on what subject to address you, with which you are not already more fully acquainted than myself; and if I make suggestions which may seem out of place, allow me to plead a simple desire to impart what I possess, whether common to us or not.

First and foremost I suppose among the topics which most interest mechanical engineers is the Steam Engine itself, to the study of which this Institution may boast that it has contributed in no small degree by its recent investigation into the practical relation of the horse-power developed to the steam and boiler power needed for its development. Nothing could be more confusing than the method hitherto in use for determining the efficiency of marine engines by a mere reference to the coals consumed on a voyage, no regard being paid to the nature of the boilers, their evaporative power, the steam connections, the degree of expansion of the steam, the perfection of the condensation &c., all of which seem to have been merged into three factors—coal consumed, cargo carried, and length of voyage. The recent experiments on the s.s. "Meteor" have gone far to get rid of this confusion, and to establish

practically the real relation between the water evaporated in the boiler, the water which in the form of steam fills the cylinder in its expanded condition, and by difference the steam which actually condenses and is lost in the course of the stroke. This is at present mixed up with what is condensed in the steam-jacket; but here again our Institution is investigating by a separate committee the benefits of the steam-jacket; and doubtless they will consider the question of whether it is better to heat the steam-jacket by heated gases rather than by steam. The outcome of such researches as those which have already been made cannot fail to redound to the credit and renown of our Institution, whilst enabling engineers to separate the duty of the boiler from that of the engine, and so to know which, if either, is at fault, and the extent to which it is at fault. It is only proper here to call to mind the advantages that must arise out of this important system of original research, to which this Institution has most wisely committed itself. There are points of practice which can be investigated only by a body combining practice and theory in such a way as to make their work a standard of reference for future progress.

It must be painfully confessed, I think, that there is sad neglect of land engines and boilers in respect of obtaining the highest economy of steam, as for instance in the employment of cylinders too large for the work they have to do; of connecting pipes too small between boilers and engines; and in the omission to call in the aid of the mechanical engineer as often as ought to be done, in order to effect economies in large and small establishments, economies which, in consequence of the invisible character of the steam to be dealt with, are out of sight as well as out of mind.

In respect of non-compound Locomotives, attention may be drawn to the improvement made in getting rid of the exhaust steam to prevent the choking of the outlet, a condition which threatened to prevent the further development of speed on railways. By increasing the area of the exhaust passage, and dividing it into two branches—one of which allows half the exhaust to pass away as usual, while the other by a descending passage partially embracing the cylinder

permits the escape of the other half into the exhaust pipe through a more circuitous route—this difficulty was surmounted in one or more of the engines which accomplished the remarkable feats of 1888 in the celebrated runs to Scotland, when a speed as high as seventy-five miles per hour was attained on some portions of the journey. The Institution has recently had under discussion the important subject of the compounding of locomotives, and it seems extremely probable that in the coming summer the respective merits of compound and non-compound locomotives will be fairly tested by the competing railways. There appears to be little doubt that compound locomotives show a fuel economy of 12 to 14 per cent., and in one case 23 per cent. has been named; but there seems to be some difference of opinion as to how far the economy of 12 to 14 per cent. is due merely to the employment of the higher pressure of steam, and whether a like economy is not obtainable by raising the boiler pressure 20 lbs. in a non-compound locomotive. The balance of evidence seems to show that the economy is due to the extra pressure of steam, but that this extra pressure cannot be efficiently employed without compounding, on account of the greater range of temperature occurring in the pair of single cylinders, and the consequent greater waste from condensation, and the greater strain on the working parts from the higher pressure of steam in two equal-sized cylinders than in the small cylinder of a compound engine. Stress is laid by the advocates of one small and one large cylinder of the Worsdell and v. Borries type on the fact that strains are reduced and a softer exhaust is obtained. It is to be hoped the subject will soon receive further consideration at the hands of the Members of our Institution, and that the comparative merits of the various systems of compounding will be brought fully under our notice.

Electricity has further come to the aid of the mechanical engineer in the railway system, two remarkable illustrations of which our Members had the opportunity of witnessing last year at Bessbrook and Portrush in Ireland, giving promise of larger and more general application of this power, when circumstances favour its cheap production by proximity of waterfalls or cheapness of fuel.

In connection with this subject of locomotion may be mentioned the increasing development of the endless-rope system for the movement of tramcars in towns and cities. Nowhere has this development attained to such a pitch as in the United States. At San Francisco the steepest gradients on which houses can conveniently be built are provided with the wire-rope system, and so the houses at the top of the slopes are made as accessible as those at the base; just as in the houses themselves the upper storeys, by aid of the American elevator, are made as accessible to the tenants as the lower. In Chicago the wire-rope system has attained a marvellous development; and in one case, if I remember rightly, a clear run of five miles is obtained from one engine plant.

Now that the question of increased cheapness of transport is engaging the attention of the commercial world, the fact of past neglect of the Waterways, which, through the genius of our Brindley, Telford, and other engineers, we once possessed, is evident, and makes it imperative that the development of this the least costly means of conveyance must be the policy of the future, if we are to hold our own against the nations of the world, and supply ourselves to the best advantage. The means of propulsion for boats and barges along existing and future waterways is one which is already engaging the serious attention of mechanical engineers, and opens up a field of investigation promising to bear valuable fruit to the discoverer of the simplest and most effective motor capable of easy removal from one canal boat to another: so that, if the boat is laid aside, the engine may be usefully employed. It is hoped that at our Paris meeting some valuable information may be placed before the Members on this question of propulsion. Our French neighbours are themselves busy in efforts to solve the haulage or propulsion problem, the conditions of which are well summed up in the Journal of the Society of Arts, 7th September 1888, page 1035, in the following suggestions:—"That practical and scientific experiments be made in order to ascertain the most suitable forms and proportions for boats used in the great traffic on inland waterways; that these experiments be carried out under the direction of the governments

interested in the progress of inland navigation, and according to a uniform system to be previously agreed upon; and also (to ascertain) the best means of propulsion, either forming part of the boat or independent of it, which best fulfil the conditions of speed, regularity, and cheapness." Among the existing means of propulsion may be mentioned: — self-propulsion by steam, with screw or paddle; and propulsion by aid of a submerged chain or rope, gripped by the tug. With either of these methods it is stated that haulage of barges by a locomotive running along the bank compares unfavourably. In the meantime the urgency of the solution of the problems of increased facilities for water-transport in this country, and of the best methods of propulsion, is rendered evident by the enormous advantages possessed by other European countries—Holland, Belgium, France, and Germany—in comparison with Great Britain; whilst the Americans have made great strides in the same direction. I saw it stated in the Iron and Coal Trades Review, of 23rd November 1888, that up to 1883 France had spent over £42,000,000 on her rivers and canals combined; and there can now be no doubt that waterways have a great future in our country, in which, during the fifty years following on the construction of the Bridgewater Canal between Manchester and Liverpool, three thousand miles of canal were made at a cost of £50,000,000.

The Canals that are immediately needed in England should be constructed, or where already existing should be enlarged:—first, from London to the Midland Counties, Birmingham, Wolverhampton, Dudley &c., and from thence to Liverpool, possibly by junction with the Manchester Ship Canal; second, from the Midland Counties to Gloucester; and third, from the Midland Counties to Hull. These canals should be of a character differing in many important points from the miniature canals now in use. They should be walled in, to prevent the wash of boats and barges from doing injury to their banks. The government should provide carefully and stringently that these canals should be absolutely beyond the influence of railway companies. Trades of the Midlands now in a semi-decaying condition would spring into new life; and a new and permanent impulse would be given to numberless industries and to the general trade of all that part of

England. The capital for such operations would be readily found, if only the government recognised the claims on them, as they do elsewhere, to encourage such works, either by advancing the money at a low rate of interest, say 3 to $3\frac{1}{4}$ per cent. per annum, or by guaranteeing a minimum dividend of 3 to $3\frac{1}{4}$ per cent. on the necessary capital. In either case the government would decide on the route of the canals and upon the amount of the capital, and would nominate commissioners to represent government interests. Should the government advance the money rather than guarantee the interest, then, inasmuch as the government could raise the amount at $2\frac{3}{4}$ to 3 per cent., they would make a profit of $\frac{1}{4}$ to $\frac{1}{2}$ per cent., which would cover expenses and leave a profit to the exchequer of the country. Should the government prefer to guarantee the 3 per cent. interest, the value of the security would be equal to that of consols; the risk would be infinitesimal; the profit earnings might be fairly expected to do more than cover the 3 per cent. interest and the $\frac{1}{4}$ per cent. extra for government expenses if agreed; and the government would at least reserve to itself the right to make up the deficiency of any one year out of future earnings. Why should the government refuse? The work is a national work, and the principle of government advances is conceded in such examples as the Suez Canal, local improvements, education, Irish landlords, and numberless other instances. Why should England in this respect be behind foreign governments, nearly all of which guarantee a minimum dividend on important national undertakings? This policy has been adopted in India, the government there freely entering into such obligations, and finding such a course greatly to the advantage of the country and the government. Nay more, the government in India not only guarantees minimum dividends on projected railways, but in some cases offers to work the railways by providing rolling stock and maintaining the lines, upon having assigned to itself 50 per cent. of the gross receipts. Such an example is to be found in the railway to be constructed from Delhi *viâ* Kurnal and Umballa cantonment station to Kalka at the foot of the Simla Hills, at a cost of £800,000, exclusive of £300,000 debentures. In this case no dividend is guaranteed; but it must be

admitted the proposed arrangement is an excellent equivalent, and shows the active manner in which the government takes part in and assists works of great public importance. Why not then take part in these proposed canals, which are to restore the trades and manufactures in various parts of the country and to promote those already existing?

Nor need our view be limited to the growing importance of the question of canals, and to the activity of our near neighbours. Developments with which mechanical engineers must be intimately associated are taking place in every country and every quarter of the globe. Science is ever making more rapid progress; wealth all over the world is increasing in proportions undreamt of by our fathers; gold and silver discoveries and the mining of copper have called into play a class of machinery which has rendered profitable the working of mines hitherto untouched; whilst the products of the vast industries in progress all around us are annually adding largely to the wealth of nations, so that new wants, calling for the aid of the engineer, are everywhere being created. More especially is this the case in connection with the republics of North, South, and Central America, and with Mexico and her federated states, scarcely inferior in number to those of her great neighbour, and certainly not inferior to the United States in the wealth which is now on the eve of vigorous and practical development. Mexico is about to cover her territory with railways, harbours, piers, gigantic drainage works, bridges, viaducts, tramways, &c.; and is also requiring the necessary machinery for her mining and commercial enterprises. Chili and Peru are also moving forward with new sources of wealth and in the same direction as Mexico, the nitrates being far greater revenue producers than the famous guano deposits of Peru. What has for ages been a productive petroleum field in Peru, considering how crude have been the means hitherto employed for working it, is now being opened with modern machinery, and is already yielding large quantities of oil and gas from flowing wells; it may indeed probably rival both American and Russian fields, owing to the enormous advantages it possesses in distance and other respects for the

Chinese, Australian, and Indian trade. The Argentine Republic and other states are also at this moment addressing themselves to Europe for capital and for scientific assistance. Among the other states may be mentioned Venezuela, where a railway is in course of construction from Barcelona, running sixteen miles inland to open up a coalfield in a chain of mountains, in which the coal crops out in the hillside; the coal is to be shipped from the Puerto de Guanto, a port thirteen miles distant from Barcelona by rail. Even in Europe, Spain is at length waking up, and is now raising large sums to complete works which require the skill and co-operation of the engineer, and is giving subventions for her railways.

In addition to all this, it is now clear that China and Japan have at length commenced, and are prepared to embark on, a career of railway, harbour, and bridge work, which may soon attain colossal proportions; and last of all, through the explorations of Captain Wiggins, of Sunderland, and the generous concession of the Russian government to Sir Robert Morier, there is now the promise of opening up through the river channels of the Obi and Yenisei the almost unrivalled cornfields and gold-bearing rocks of Siberia. For these and other reasons too numerous to mention, the profession of the engineer must be regarded as one of daily increasing importance, especially when we remember that an English engineer is well received and relied upon in every part of the world.

In reference to the present attainments of the engineer, whether in boldness of conception and magnitude of the work, or in the methods adopted for its execution, an example may be quoted in the wonderful structure of the Forth Bridge, so ably designed by Sir John Fowler and Mr. Benjamin Baker to avoid all necessity for supplementary centering, and to make every completed portion of the work serve as the requisite staging for further erection. In no other way does it seem possible that the huge bridge could have been constructed to span the two largest openings in the world of 1,700 feet each between pier and pier.

The Eiffel Tower at Paris, nearly 1,000 feet high, seems to have been designed for the world's fair of 1889 in Paris, to show how

even the high towers of the Forth Bridge, rising to 361 feet above high-water level, can be outstripped in a veritable tower of Babel of twice the height of any existing monument. The top of the tower is made accessible by elevators, of which I hope a description will be given to the Institution in Paris.

For boldness of design, combined with the greatest delicacy of manipulation, may be mentioned that wonderful telescope erected at Mount Hamilton, California, at the Lick Observatory, so named after its founder, James Lick. The floor of this observatory is $61\frac{1}{2}$ feet diameter and weighs 22 tons, and is movable vertically through a range of $16\frac{1}{2}$ feet between two fixed galleries (see *Engineering*, 31 Aug. 1888). The upward movement is accomplished by hydraulic rams in ten minutes, and the downward in five minutes. This arrangement has dispensed with the use of a lofty and inconvenient series of step-ladders, and the idea of a rising and falling floor is due to the inventive genius of a countryman of ours, Sir Howard Grubb, of Dublin, who was consulted about the difficulty of arranging for an observatory of such exceptionally large dimensions. It is not improbable that all the movements will ultimately be controlled by electrical connection from the observer's hand, acting on hydraulic machinery. The roof consists of a steel dome 75 feet diameter, and the weight of its moving parts is 88 tons. The tube of the telescope is 52 feet long, tapering from 4 feet diameter in the middle to 3 feet at either end.

Of works in progress may be mentioned the construction in this country of two hydraulic lifts to raise ships weighing 2,000 tons out of the water, to a height of 40 feet, to be transported by railway a distance of 17 miles before being again lowered into the water. The lifts will be erected at Halifax, Nova Scotia; and the railway will connect the head of the Bay of Fundy with the Gulf of St. Lawrence. The chief engineer of this work is Mr. Benjamin Baker.

Among developments which may be attributed mainly, if not entirely, to the inventive faculty of the mechanical engineer, and which give him the power to carry out these wonderful structures, may be mentioned the extension of the application of power

machinery, such as the hydraulic machinery now employed for performing the effective riveting of large thicknesses in situations which would otherwise be impracticable; for forging by pressure, and for the only thorough system of welding by uniform pressure through the mass in place of surface hammering; and for curving plates, from armour plates to Forth Bridge plates. At the Forth Bridge works the application of hydraulic power has been carried to the remarkable extent of effecting the continuous riveting together of large steel plates forming an average thickness of from 3 to 4 inches through the joints, in positions extending to a height of 350 feet, and stretching out over the water to a distance of 500 feet; ultimately 680 feet distance is contemplated. The riveting is done by small portable machines working with a pressure of 1,000 lbs. per square inch, and in exceptional cases up to 3 tons per inch; and the power is conveyed to them by small jointed pipes from the engine and compressing pumps on the ground below. In connection with the application of hydraulic pressure, mention ought here to be made of a system which dispenses with the necessity of accumulators, and which my firm has had in operation at Woodside Iron Works for many years. It consists of a three-throw pump driven by shafting or worked by steam, and depends partially upon the work accumulated in a heavy fly-wheel. The water in its passage from the pumps and back to them is in constant circulation at a very feeble pressure, requiring a minimum of power to preserve the tube of water ready for action at the desired moment, when by the use of a tap the current is stopped from going back to the pumps, and is thrown upon the piston of the tool to be set in motion. The water is now confined, and the driving belt or steam engine, supplemented by the momentum of the heavy fly-wheel, is employed in closing up the rivet, or bending or forging the object subjected to its operation. The inventor of this very useful and simple application of hydraulic pressure is Mr. Andrew Higginson, of Liverpool. Hydraulic power has been successfully applied to the bodily lowering and raising of great turret-guns, and most usefully to do the work of buffers at the ends of railway sidings.

The substitution of Triple Expansion marine engines for double expansion is as marked a step in the history of mechanical progress as was the previous substitution of double expansion for single expansion, to which special reference was made by our Past-President, Sir Frederick Bramwell, at the Liverpool meeting of the Institution in 1872 (Proceedings 1872, page 125). It is a striking circumstance that at that time, as then described by him, the pair of single-cylinder engines previously used was being rapidly replaced by a pair of compound engines in the large steamers; and single engines that were even nearly new were being sacrificed for the purpose of realising the great saving of fuel obtained with the compound engines, and the attendant gain in increased cargo space. And now, after another fifteen years' experience, these two-cylinder compound engines have in their turn been again discarded for the further step of three-cylinder engines, having triple expansion instead of double expansion, and a consequent still further saving of fuel. One of our Vice-Presidents, Mr. Adamson, has been bold enough to predict the following up of the triple by quadruple expansion, as the necessary outcome of the benefits derived from each of the previous stages.

In the development of Marine Engineering during the past fifteen years or more, notice ought to be taken not only of the increased and growing dimensions of the hulls of vessels, but of the admirable application of steam power to the control of the rudder, enabling the work of steering a large vessel to be now controlled by one man, where in rough weather, or where manœuvring is required, four or more men would otherwise be needed; besides which, that one man is in close proximity to the captain on the bridge, instead of having several men all at the stern, removed from him by half the length of the ship, as was the case formerly. This is an excellent illustration of how one improvement leads on to another, without which it might be difficult or impossible to work out the first; and so progress is rendered possible by the mutual adaptation of every part to the whole. The admirably simple and ingenious differential gear originally invented by our Member, Mr. J. Macfarlane Gray, for steering the Great Eastern, and now so extensively applied in large steamships, was described in his paper

to this Institution twenty-two years ago (Proceedings 1867, page 267).

In this connection mention may be made of the beautiful invention of Sir William Thomson for taking soundings, in which he avails himself of the compression of air in a glass tube of small diameter, coated inside with a colouring matter consisting of chromate of silver, which is immediately destroyed by the contact of sea water. The glass tube is protected in a brass case, and is attached to the sounding line a little above the customary lead. It will be seen that as the instrument descends, the tube being open at the lower extremity and closed at the upper, the air is compressed in it in proportion to the depth of water; and a permanent record is retained of the amount of compression, by the undisturbed colouring matter left in the upper part of the tube. The beauty of this simple invention is that it acts irrespective of the angle of the sounding line.

Nor ought Railway mechanical improvements in general to be overlooked in any reference to progress made. The remarkable development of locomotive working, and the high degree of perfection to which it has attained, could not have been reached without collateral improvements to ensure the safe working of the high-speed through-trains on thronged main lines. These improvements are to be found in the mechanical interlocking of signals and points, and the mechanical contrivances of continuous brakes; the increased weight of rails from 65 and 75 lbs. to 85 and 90 lbs. per yard, and the substitution of steel for iron; the adoption of the ingenious and simple plan devised by our Past-President, Mr. Ramsbottom, for refilling the tender tank whilst running at full speed, by scooping up the water from a long trough laid down between the rails; the doubling of the lines of rails, in order to separate the slow from the quick traffic; and the means of communication between passengers and guard. Mr. W. P. Marshall, in calling attention to many very interesting points on modern railways in a paper read before the Birmingham Philosophical Society—I may here mention that I am indebted to Mr. Marshall for several valuable hints—sums up his observations with one to the effect

that the present annual rate of increase in the total railway mileage of the world is more than seventeen thousand miles, and is equal to nearly as much as the whole railway mileage of this country, "showing a good promise of business to come for the numerous manufactures that are concerned in the making and working of railways."

The next point to which I would fain direct attention is the great room for improvement in the Sanitary arrangements of towns and houses. These are essentially engineering questions, and have not hitherto received the attention they merit. It is difficult to name a town in which the application of a new drainage system has not left foul evidence of the nuisance it has been supposed to remove. Although by carefully trapping the house from the sewer the more immediate danger of perpetual inhalation of sewer gases has been removed, yet the open sewer grates in the streets, without any attempt at real ventilation, emit the foul smells of the sewer into the street. The worst case of this kind which has come under my notice was at Lincoln, where the ground is so flat, and the fall to the pumping engines so slight, that it may readily be imagined a semi-stagnant condition of the refuse in the sewers may exist. But not at Lincoln only are such nuisances to be found, and, if in lesser degree, not less offensive. At Eastbourne a few years ago the discharge of sewage at low water, through the mouth of the main sewer itself, led between tides to the pounding back of the sewage and the compulsory forcing of the pent up gases into the streets. This I am told has since been remedied. At Bournemouth the sewage is delivered out beyond the end of the pier, through a pipe laid on the bed of the sea. The lighter specific gravity of the water passing with the sewage causes it to reveal itself by a large sheet of foul water spreading out visibly over the denser salt water. This area of sewage water is generally rendered further conspicuous by the presence of a large number of sea gulls, which are not infrequently known among the residents as the Bournemouth scavengers. It will be obvious how such a system is to be reprehended, when the effects of an in-shore wind are considered. At that time the gulls are to be seen as busy on the waves breaking on the beach, as at other times over the

mouth of the pipe which is supposed to convey the sewage safely away from the beach of that charming seaside resort.

The imperfections of the great system of drainage forced upon London are well known; and it is strange that, at the very centre from which emanate the laws providing for the non-pollution of rivers, the worst example probably in the world should be found of a river polluted at one time to such a degree as to make it impossible for legislators to remain at their posts, and at present offering in its course an example of filth which it would be difficult to surpass. To get rid partially of the nuisance in London by delivering it into another portion of the Thames at Crossness, only some few miles lower down, betrays an imperfection which will some day need further correction. According to Dr. C. R. Drysdale, who read before the last meeting of the British Medical Association at Glasgow a paper on the subject of the disposal of sewage of large cities, London is at the present time throwing away sewage to the value of £1,000,000 per annum. He quotes Sir Robert Rawlinson as saying that the sewage experiment of London is a failure, whilst the cities of Berlin, Dantzig, and Breslau, with an aggregate of 2,000,000 inhabitants, have enjoyed the benefit of successful sewage farms for fifteen years past. In London every day there are poured into the Thames 150,000,000 gallons of sewage, the proper destination of which should be the soil.

New York, lying between Hudson and East Rivers, is guilty of precisely the same fault we formerly committed in London, and as assuredly will be driven, as London was, to protect itself against the increasing mischief of polluted rivers on the two sides of the city. The only perfect example of drainage of which I am aware is that carried out at Pullman near Chicago, where the Palace Car Company had the advantage of laying out the town at the same time as their works. The site lying low and close to the edge of Lake Calumet, drainage into the latter would have been objectionable, to say nothing of the certainty of future mischief arising from a polluted shore. The drains preceded the population, and were laid out with a view to lead the sewage water to a pumping engine considerably below ground level, and the sewage is thence pumped to a farm

three miles away; in this there is no novelty. The novelty consisted in establishing a system of ventilating the sewers into a high stack, the draught of which is sufficient not only to do all the work of the establishment in raising steam, but to effect the ventilation of the sewers, the gratings of which admit fresh air from the streets, instead of discharging foul air into them. I am only sorry my short visit prevented me from obtaining fuller information on this interesting development of sanitary engineering. The population of Pullman is now 11,000, and the area covered by town and works is 300 acres; the death rate in 1887 was as low as nine per thousand. At Nottingham in this country the sewage is delivered out to a farm several miles away; and the storm or surface water, as is the case at Pullman, is conveyed by separate channels to the ordinary watercourses. This is obviously a point of great importance, but unhappily not always attended to. I learn that in London at the Houses of Parliament a thoroughly mechanical method of disposing of the sewage is at work, on what is called the Shone hydro-pneumatic system, and that this method has been used for several years at various places in England; but regret I have no personal acquaintance on which to base a reliable opinion. I am led to mention it, from the circumstance that a friend at Chicago has written me to say they are about to introduce it into that city. What London, and for the matter of that all towns, ought to be, was well set forth in a lecture delivered some months ago to a London audience by Mr. Frederick Harrison:—" It must be a city where our noble river will flow so bright and clear that the young people can swim in it with pleasure; where we shall again see the blessed sun, and clear blue sky, and the towers and steeples rising aloft in the bright air; a city which at night will be made as light as day with electric lamps, and in whose midst fountains will pour forth water from the hills of Snowdon or Helvellyn; a city where noxious refuse will be unknown, and where no deadly exhalations will be pumped into homes; a city where typhus and typhoid and small-pox will be as rare as the plague, and as much a matter of history as the leprosy; a city where the dead shall be no longer a terror to the living; and where preventible disease will be a crime

chargeable to some one, an opprobrium to the district in which it breaks out." How remote are the possibilities of realising one of Mr. Harrison's dreams of the future, not only for London but for other populous places, as expressed in the hope that the dead shall cease to be a terror to the living, may be judged by the persistence with which a prejudiced public, supported in their resistance to change by those in authority, refuse to substitute, for the poisonous system of slow combustion of the body in the grave, the truly healthy system of quick combustion by cremation. In this direction Sir Henry Thompson has been working for the past fifteen years, with slow but increasing success. That the mechanical engineer has a vast future before him in helping to realise Mr. Harrison's dream of London's future is certain.

Our late Past-President, Sir William Siemens, pointed out how great was the reformation needed in the adoption of a system for perfect combustion of the fuel employed for heating and warming our houses, as a remedy for the existing clumsy method of burning coals extravagantly in an open fire-grate. Our Member of Council, Sir Douglas Galton, has done excellent work in showing how even with an open fire-grate real warming of fresh air in a room may be effected: so that, instead of cold air rushing in to create draughts, a plenum of warm air shall meet and greet any one entering the room. This reduces the quantity of coal, at present needed to warm a room imperfectly by little more than the effect of radiation; and prevents the considerable bulk of the heat from passing up the chimney, and carrying with it smoke and dust to add to the two million particles already established by Mr. John Aitken, of Falkirk, as existing in a cubic inch of air, before a shower of rain falls and reduces their number to half a million. The smoke and dust so discharged are attended with the further disadvantage that in case of fog every particle is in danger of becoming covered with a pellicle of tar, or some oily and irritating product from the distillation of coal in an open fire.

Great work has already been accomplished in the direction of sanitary improvements by the provision of abundant supplies of fresh

Water to many of our towns and cities; and our Institution has been privileged to visit some of the largest Water Works at Glasgow, Edinburgh, Dublin, and Manchester, whilst still larger are in progress for the supply of Liverpool from the mountains of Wales, and for the further supply of Manchester from Lake Thirlmere. Unquestionably it is better to obtain pure water at its source; but what it will cost is always the precedent enquiry; and it may be well to ask whether the more or less contaminated water of our rivers can be purified, so as to be made really potable.

In 1883 our Members were invited, on the occasion of our memorable visit to Belgium, to see an attempt there in progress to accomplish the purification of the water for the supply of Antwerp. Few I fear were able to avail themselves of the opportunity thus afforded to see the attempted application on a large scale of Professor Bischof's system of purification by means of spongy iron, which has been worked out so successfully on the small scale of domestic filters. Though correct in principle, the application of the spongy iron over large areas led after some months to the obstruction of the filter beds, and would have compelled the abandonment of the system, had it not been for the bold and radical change which it occurred to our Vice-President, Mr. William Anderson, to introduce. The spongy iron was removed from the filter beds, and the reservoirs containing it were transformed into sand filter beds, on which oxide of iron speedily forms and plays an important part in the purification of the water passing through it. Sir Frederick Abel appears to have suggested the application of ordinary metallic instead of spongy iron; and Mr. Anderson seems to have worked out the idea most successfully in his application of what is known as the revolving iron purifier, which has now been in operation for over three years at Antwerp. On the authority of Professor Ad. Kemna, who was appointed chemist to the waterworks, I am able to state that so complete is the satisfaction given that similar means are now in operation at Gouda and Dordrecht in Holland, and at the establishment Cail, Quai de Grenelle, in Paris. Experiments on a large scale have been made at Ostend, Berlin, and in London. In view of the success attained in purifying the water supplied to Antwerp, Professor Kemna is

hopeful that by the employment of those revolving cylinders it will be possible to render inodorous the effluents of the sewers, and thereby make them sufficiently pure to deliver into streams or rivers without serious consequences. On the authority of Mr. Anderson, I learn that the system is to be applied at Baroda in India, and that the municipality of Agra has adopted it for purifying the waters of the Jumna, and that the town of Libourne in France is also applying it. It is an interesting circumstance in connection with the purity of the water now obtainable at Antwerp, that some of the steamers sailing thence to New York take in a supply for the double voyage, in preference to refilling from the Croton aqueduct at New York for the return voyage.

In Blast-Furnace practice mention should be made of the development which has taken place in the now almost universal adoption of fire-brick stoves, and with them the application of such high temperatures of blast to the smelting of pig iron as are impossible of attainment by the use of cast-iron stoves. Economies have thus been realised of 3 to 4 cwts. of coke per ton of iron, according to the less or more favourable conditions under which the furnaces were working; whilst, by the substitution of lime as a flux, instead of limestone, economies of 2 to $3\frac{1}{2}$ cwts. have been rendered possible, according to the circumstances of its employment. In American blast-furnace practice the combined application of high temperature and pressure of blast, the latter reaching 9 to 10 lbs. on the square inch, has enabled our American cousins to outstrip us in the magnitude of their outputs of pig iron, which in the case of the celebrated Edgar Thomson furnace F has exceeded 1,900 tons in a single week with an ore containing 60 per cent. of iron.

In this connection may be named the enormous progress which has been made in the manufacture of iron since the days when Lord Sheffield in 1786 commented in the following terms upon the erection by the Earl of Dundonald near the Calcuts on the river Severn of a row of stew-coal ovens (see John Randall's 'The Severn Valley,' page 317):—"If Mr. Cort's ingenious improvements in the art of making and working iron, the steam engine of Boulton and Watt,

and Lord Dundonald's discovery of making coke at half the present price, should all succeed, it is not certainly too much to say that the result will be more advantageous to Great Britain than the possession of the thirteen colonies; for it will give the complete command of the iron trade to this country, with its vast advantages to navigation." The object of Lord Dundonald was not only to cheapen the cost of coke, but also to obtain tar for the navy; and this he did by condensing it in chambers cooled by water. Every one knows how since then the tar has been made the source of many and valuable by-products, and how various systems of coking have been introduced, having special reference to larger output of coke and greater economy of the products of distillation. Where the latter are not sought for, as in the large coking collieries of the North of England, the old bee-hive oven of 10 to 11 feet diameter still retains the ascendency; and I know of no greater improvement than that of the introduction of heated air into the body of the gases as they are evolved from the coking mass.

As a further contrast between the state of things in 1786 and 1889 may be mentioned the difficulty Boulton and Watt had to obtain a cylinder bored out truly. In their dilemma Mr. Watt sought an interview with Mr. Wilkinson of Broseley, who had acquired such proficiency in the joint art of founding and boring cylinders truly that Messrs. Boulton and Watt were induced to place an order with him to cast and bore a dozen cylinders of diameters varying from 12 inches to 50 inches, and a like number of condensers of suitable sizes, the latter to be sent to Soho to be kept ready fitted up, so that an engine could be turned out of hand in two or three weeks: Mr. Boulton's ideal of work at that time being to turn out twelve to fifteen reciprocating and fifty rotary engines per annum. Nowadays Messrs. Baldwin and Co. of Philadelphia turned out from their works during the past year no less than 737 locomotives.

Another point of improvement which must certainly not be passed by unnoticed is the recognition by engineers generally of the sufficiency of hot-blast iron to meet most of the demands where cast iron is usually employed. There is a point however which

engineers ought to take into their serious consideration in the employment of cast iron, and which at present is occasionally ignored. I refer to the impossibility of running a small thin casting with the same metal which is proper for a larger casting. Although made from identically the same materials, the lower numbers or grades of pig iron are weaker than the higher numbers, and it is out of the lower or grayer numbers that small articles must be cast. Again in proving cast-iron pipes, the stipulation that, when under pressure, they are to be struck with a hammer possibly of 5 lbs. weight, without reference to the force of the blow, raises a serious doubt about the damage a pipe sometimes sustains by the extra force employed beyond that needed to throw it into the requisite vibration. Where the blow struck is too violent, it by no means follows that the pipe will yield to the extent of bursting; but it will become starred or cracked on the inside, at the point at which the blow has been struck, and to that extent the material has suffered permanent injury. The real test should be the pressure from within, supplemented by such a blow on the pipe as shall not endanger the integrity of the sound metal, but sufficient at the same time to ensure that any existing flaw or defect shall be immediately revealed. In the testing of wrought iron it has long been recognised that for permanent structures no metal in its proof should be strained to such a degree as to produce a permanent set; and the same principle seems to admit of ready application to cast iron as well.

It is perhaps not out of place here to refer to the recent progress made in the preparation of Aluminium, and the attempts to employ it in alloy with the more infusible descriptions of iron. The presence of one part of aluminium in eight hundred parts of steel appears on the authority of Admiral Kolokoltzoff, the director of the gun factory at St. Petersburg, to set the steel entirely free from air bubbles, as the simple outcome of lowering its melting point. In the preparation of the celebrated mitis castings, Mr. Nordenfelt appears in like manner by the employment of 1–2,000th to 1–700th part of aluminium to have succeeded in lowering the melting point of nearly pure iron so as to enable it to be run into moulds.

One more point to which the attention of mechanical engineers should be directed is the superfluous insertion in specifications, not only of the conditions to be complied with, but also of the means by which those conditions are to be attained. The two stipulations are sometimes incompatible with each other; and, even if only in a minor degree, mechanical engineers would save themselves much trouble, were they simply to impose their conditions, and to insist on these and these alone being carried out, irrespective of the means by which they shall be faithfully fulfilled. Perhaps some one will remember to have seen the condition imposed that test bars 3 ft. × 2 ins. × 1 inch shall *stand* a certain weight, when the real meaning is that they shall not break with less than that weight. I crave the indulgence of the Members if it seem hypercritical to call attention to such defects; but it will be obvious that to stand a certain weight may mean something very different from the condition of not breaking with less than that weight.

In the improvements made in Testing all kinds of iron, the progress during the last few years has been great; and it is to be hoped that the existence of reliable machines will lead engineers to be content with their records, rather than return to the old system of dead weights, which are so cumbersome to move and so difficult to handle with safety. In Wicksteed's machine we have seen a fine example of the application of enormous power by single leverage (Proceedings 1882, page 384). In Emery's we have seen the power applied by fluid pressure in a thin film, and that power measured in the most delicate balance, detailed descriptions of which have been recently given to the Institution, and are recorded in our transactions (Proceedings 1888, pages 206 and 448). In the application of hydraulic pressure as formerly employed for fracturing wrought iron, the method of measuring the force was by the employment of a plunger and lever, the friction on which was so great as to lead engineers to specify as high a breaking strain per square inch of metal as 24 tons. When the fluid pressure was measured by a more delicate instrument, it was found that instead of the iron being really able to carry 24 tons it could carry only 22 tons.

The next point to which I would direct your attention is the Deterioration to which wrought iron is exposed when subject to the influence of rain water: as exhibited in bridges constructed over the Thames, the waste being aggravated doubtless by the acid condition of the atmosphere, due to the presence of sulphurous acid from coal as well as to the customary percentage of carbonic acid. In the course of five-and-twenty years bolts have been eaten away from a former diameter of seven-eighths of an inch to half an inch diameter, being a reduction in area of 67 per cent., and this in a portion of the structure where the brackets of an overhanging footpath were supported in part by the decaying bolts. In like manner bolts originally five-eighths of an inch diameter, which supported overhanging ornamental work, have been corroded down to a diameter of five-sixteenths, with a loss of 75 per cent. of their strength. Wherever the rain trickled over the face of the girders to which the brackets were attached, the same evidence of deterioration was manifested in the scaling of the plates: pointing to the necessity both of preventing water from coming into contact with wrought iron, and of periodically examining structures of wrought iron, and painting as often as required. Many years ago Sir John Hawkshaw pointed out, and warned the public against, the inevitable deterioration of iron telegraph wires in a London atmosphere.

Another illustration of insidious destruction of iron may be cited in the case of a wire rope at a colliery, kept in reserve to wind men up and down the shaft in case of ropes breaking or of other accident preventing use of the winding shaft. Whilst at rest the "emergency" rope was subject to the drip of rain at the same spot for some years from the roof of the engine-house. External examination was strict, and the rope was regularly greased as is customary. At length a man riding up the shaft was killed by the breakage of the rope at the point exposed to the rain drip; and the wires internally were found to have been corroded to the extent of drawn-out needle-points.

It may not be out of place to refer to the danger of decay to wood, under the somewhat exceptional circumstance of forming the dry portion of a set of lifting spears in a pumping shaft, in which a slight escape of steam arose from the leakage of the joints of a

steam main. The spear was of pitch pine, 12 inches square, and had been in use seven years, when it suddenly gave way in a manner which indicated that the wood had rotted under the influence of a moist atmosphere, and of condensation of moisture within the limits of the joint of the spear rods, which were scarfed and bolted together with covering plates of wrought iron. The scarf joint was rotten on both faces; and the case points to the absolute necessity of a periodical examination of dry spears, by the removal of the spear plates and careful inspection of the joints, as well as to the desirability of avoiding the use of steam pipes, unless well boxed off, in a shaft where dry spears are in use.

Although in our papers and discussions no reference is permitted to the merits of any particular patent, it occurs to me that mechanical engineers are deeply interested as a body in the character of the laws by which their inventions may be protected. In this respect the system adopted in the United States seems to possess decided advantages over that adopted by Great Britain, where it is possible, nay easy, to take out a patent for a prior invention, because there is no such care exercised here as in the United States to see that no similar invention has been introduced previously. They make it a duty to enter upon a rigid search before permitting the patent to be filed. Here we must direct the patent agent to make the search, sometimes at considerable cost, before the applicant can know that he is not guilty of "inventing" over again what some one has already invented. In this respect I think we should welcome some improvement in our system, which, if it somewhat curtailed the business of the agent, would have the advantage of preventing a large amount of superfluous work in the patent office, and saving considerable disappointment to the public.

If I trouble you with a reference to the subject of Agriculture, it is not with a view to draw your attention to the wonderful developments of the agricultural implements with which the tilling of the soil and the gathering in of the crops have been made so easy in comparison with the old method when "Adam

delved and Eve span;" but to call attention to the larger application of such machinery to the object of converting arable land into pasture and old pasture into arable. The laws of the country are still prejudiced in favour of retaining old pasture, and on no account of permitting it to be broken up: so that we persistently refuse to recognize the teeming wealth which lies beneath such old pastures, into the soil of which the roots of the grasses do not descend more than four or five inches, whilst the roots of cereals descend to depths of eighteen inches or more, according as the breaking up will permit. The work of converting old pasture into arable is easy, if the plough alone be used; but it has not been generally recognized that in three or four years the arable can be converted into valuable pasture by the removal of the grass from the old pasture, laying it in strips upon the arable with narrow intervals between, over which, by what is called the process of inoculation, the grass spreads, and by the aid of suitable rollers is slowly but surely consolidated. At present the cost of removing the turf by hand is a serious impediment; but when once the principle is recognized by our legislature, a new field is open for the application of machinery in the shape of an improved skim-plough with appliances for rolling up the turf as cut, so as to simplify the whole process, and so that the soil below the turf shall be afterwards broken up without destroying the turf itself.

From various allusions in this Address it will be seen how intimately bound up are the interests of mechanical engineers with an enlightened legislative policy; and it behoves all of us to see that lingering prejudices shall be removed where they exist, and a fuller development of mechanical engineering be thereby rendered practicable both at home and abroad.

Mr. Edward H. Carbutt, Past-President, was sure the Members would all desire to join in a hearty vote of thanks to the President for his Address. It was not usual to discuss the presidential address, and Mr. Cochrane in his modesty had given that as one of the reasons why he had written it. From the acclamation of the Members it was evident that they had greatly enjoyed it, and that it had given them something to think about. The President had taken a line of his own; he had not followed the usual practice, but had taken up a number of subjects not usually thought about, the consideration of which would bear fruit in the future. He had said that he had roamed all over the world for his information, and those who had followed his address would agree that he had done so. He was glad to hear so much about Mexico in the address, because he had himself just returned from that country, and could fully confirm what the President had said, that Mexico was developing at a very rapid rate and was a good field for engineers. Had discussion been allowed, the question of the government finding money for canals might perhaps have been strongly debated. Without entering therefore into that subject, he would move a hearty vote of thanks to the President for the trouble he had taken in getting together all the information which he had brought before the Institution, and for his assurance that there was work for all the engineers throughout the country for many years to come. The mere fact that railways were increasing at so rapid a rate as 17,000 miles a year showed that there was plenty of work for engineers to do. With reference to the sanitary subjects to which the President had alluded, every one must wish success for all efforts towards obtaining the clear atmosphere and clear water after which the address aspired; and he hoped engineers would devote their attention to carrying out what the President had indicated in that direction.

Mr. Daniel Adamson, Vice-President, said if anything further had been needed to commend the vote of thanks for the President's admirable address he might have been induced to make a speech.

As it was, he would do no more than refer to the important subject of underground haulage for tramcars, to which he was glad that attention had been called. When they visited Edinburgh a year or two ago, many of the Members had the opportunity of seeing the tramcars there running with underground rope traction; and for hilly districts it appeared to him that the plan was highly advantageous. Rather than attempt to criticise, he preferred to express his approval of the address, in which there was so much that was deserving of approbation. They were all much indebted to the President for the wide field over which he had roamed, and for the clear way in which he had brought the different subjects before them. They would all, as Mr. Carbutt had said, remember the address with pleasure, and would ponder over it with advantage to themselves and to the Institution. It had laid a foundation for a further extension of knowledge, and would be an example to those who might endeavour to enlighten the Members on some future similar occasions. He had great pleasure in seconding the motion that their best thanks be given to the President for his admirable address; and he was sure they would all loyally support him during his presidential reign, because he had begun so well and interested them much.

The vote of thanks was passed with acclamation.

The President felt that the vote of thanks should be given through him to the many friends who had helped him to bring before the Members the information contained in his address. He could not have done it without the generous help which he received from many gentlemen, too numerous to mention, on both sides of the Atlantic. The Pullman Palace Car Company had been good enough to write to him on the subject of their arrangements, and many gentlemen in this country had also assisted him; he had already mentioned the name of Mr. Marshall, from whom he had received some valuable hints. He was thankful to have been able to compile his address, and to put forward his own views, in such a way as to receive the expression of the approval of the Members. With regard to the debatable nature of any of his opinions, he had endeavoured

(The President.)

to express them tentatively and interrogatively rather than in any tone of dictation, but none the less with a conviction that something ought to be done. He was much gratified by the kind manner in which the address had been received.

RESEARCH COMMITTEE ON MARINE-ENGINE TRIALS.

REPORT UPON TRIALS OF THE S.S. "METEOR."

By Professor ALEXANDER B. W. KENNEDY, F.R.S., *Chairman.*

Steamer.—The S.S. "Meteor" is a steamer belonging to the London and Edinburgh Shipping Company, and permission to test her engines was most kindly given to the Committee by Mr. Thomas Aitken, the manager of the company, who with his staff and all the officials on board the ship have done their utmost to facilitate the work of the trial. The "Meteor" is a vessel 261 feet in length between perpendiculars, 32·1 feet in breadth, and 19·3 feet in depth moulded. Her registered tonnage is 692 and gross tonnage 1,223, under deck 958 tons. Her displacement on the day of the trial, when the mean draft was 15 feet $1\frac{1}{2}$ inch, was 2,090 tons.

Engines.—She is fitted with triple-expansion engines, made by Messrs. J. and G. Thomson of Clydebank, Glasgow. The high-pressure cylinder, originally 29 inches diameter, has been rebored to $29\frac{3}{8}$ inches diameter, the intermediate cylinder is 44 inches diameter, and the low-pressure 70 inches; the stroke of all three cylinders is 4 feet. The piston-rods are all 7 inches diameter; the tail rod of the high-pressure cylinder is 4·45 inches diameter, and the tail rods of the other two cylinders 4·37 inches diameter. These rods have been measured; and the stroke of the engine has also been measured, and found to be exactly 47·94 inches, instead of 48. There has been no opportunity of measuring the diameters of the cylinders.*

The three cranks are spaced at equal angles apart, and follow in the order—high, intermediate, low.

* The cylinder diameters have since been measured, and have been found to be as follows:—high-pressure $29\frac{3}{8}$ inches, as given above; intermediate 44·03 inches, that is 1-32nd inch larger than above; low-pressure 70·12 inches, that is 1-8th inch larger than above.

The cylinders are made with separate liners, and are jacketed at the sides but not at the ends. The net length of the jacketed space is about 4 feet. Live steam is admitted separately to each of the jackets, each having its own reducing valve. The jackets are drained through pockets provided with gauge glasses, and during the trial water was always kept visible in these gauges. The clearances of the high-pressure, intermediate, and low-pressure cylinders are given by the makers as 12·4, 9·3, and 8·02 per cent. respectively.

Each cylinder is provided with a piston-valve or valves, single for the high-pressure cylinder, and double for each of the others. The valve gear is the ordinary link-motion, and during the trial the high-pressure motion was linked up as much as possible, giving a nominal cut-off of 26 inches; the intermediate and low-pressure motions were not linked up. The valve gear was left untouched during the whole of the trial. The surface condenser has 3,200 square feet of condensing surface. The screw propeller is four bladed, having a diameter of 14 feet 10 inches, and a mean pitch of 23 feet. The actual area of the blades is 78 square feet, and the projected area 57·6 square feet.

The engines had been overhauled last at the annual survey, which took place March 1 to 14, 1888.

Boilers.—The boilers are two in number, each double-ended, the total number of furnaces being twelve. They are of steel, with Fox's corrugated flues, and have a diameter of 13 feet 6 inches and a length of 16 feet. The total grate surface in the trial was 208 square feet, and the total tube surface 5,760 square feet, the ratio between the two being 1 to 27·7. The total heating surface is 6,648 square feet, or 32 times the grate surface. The means diameter of the flues is 3 feet 3 inches. The firebars are of ordinary description, 3 feet long, 1 inch broad at top in body, and about $1\frac{1}{2}$ inch at the ends, the air spaces being thus about $\frac{1}{2}$ inch wide. There are 25 bars in the width of each furnace, and therefore 50 bars in each grate, which is 6 feet long. There is no air admission at the bridge or anywhere except from the front and from below the bars. The tubes are $2\frac{1}{2}$ inches external diameter and 6 feet $4\frac{1}{2}$ inches long. The furnaces and tubes open out into a common combustion

chamber. The two boilers have one chimney in common, whose internal diameter is 7 feet 3 inches; the external diameter of the outer chimney is 8 feet $3\frac{1}{2}$ inches. The chimney has a total height of 61 feet above the centre of the lowest furnace.

The total weight of the engines and boilers, including water in condenser, pipes, and boilers, and also spare gear is $390\frac{1}{2}$ tons.

Object of Trial.—The object of the trial was to measure the coal, water, and indicated horse-power, as accurately as possible, and over as long a period as possible.

Coal Measurement.—For weighing the coal, a spring balance was used in each stoke-hole. From the spring balance was suspended a large basket holding about 140 lbs. of coal; this being filled was hoisted by tackle, its weight noted, and the coal then thrown upon the stoke-hole floor. About six baskets were filled and emptied as rapidly as possible one after the other, first on the starboard side and then on the port side of the stoke-hole floor, giving thus two weighed heaps of about 800 lbs. of coal each. The time at which each heap was finished (that is, completely put on the fires) was noted, and no more coal was weighed out until the floor was clear. A continuous record of coal thrown on the fires was thus kept, which plots out into the line of coal consumption shown upon the diagram, Fig. 1, Plate 45. The fires were not cleaned during the run, but the cleaning commenced when the trial was over, and the ashes and clinkers were weighed before being thrown overboard. The coal was Scotch from the Shawfield pit in the Wishaw district, its price at Leith being 7*s.* 6*d.* per ton. It has been analysed and its calorimetric value determined by Mr. C. J. Wilson, F.C.S., of University College, London, with the following results:—

Carbon	70·31	per cent.
Hydrogen	4·88	,, ,,
Water	10·68	,, ,,
Ash	3·46	,, ,,
Nitrogen, Sulphur, and Oxygen . . .	10·67	,, ,,
	100·00	

2 A 2

These figures are the mean of two almost identical analyses. Reducing the hydrogen to the corresponding value of carbon, each pound of coal, not allowing of course for the bad lumps which formed the greater part of the clinker, is thus equivalent to 0·878 lb. of carbon, and its calorific value may be taken as 12,790 thermal units.

Furnace Gases.—The temperature of the gases passing up the chimney was observed at intervals throughout the trial, the thermometer used being placed at the level of the upper deck, or about 12 feet above the top of the boiler. The thermometer was long enough to reach over 2 feet into the chimney. It was a mercury thermometer having the space above the mercury filled with compressed nitrogen, so as to enable it to give readings far above the ordinary boiling point of mercury.

Samples of the gases from the chimney were collected during the trial, and placed in sealed bottles over mercury. Unfortunately however all the samples taken except one were spoilt before they reached the laboratory for analysis. The analysis of this sample has been made by Mr. C. J. Wilson, and is given later on (page 241).

The chimney draft was measured by a U gauge at the place where the furnace gases were collected.

Feed Water Measurement.—The feed water was measured on its way from the hot-well to the feed pump, the latter being a Worthington pump entirely separate from the engine. A 4-inch pipe was connected with the hot-well, and terminated in a 4-inch two-way cock, by means of which the discharge could be turned into either one of two measuring tanks. At the bottom these tanks were connected to another 4-inch two-way cock, through which the feed pump could be made to draw from either of them. The tanks were so tilted that one corner was lower and another corner higher than all the rest, so as to render their filling and emptying more certain. They were fitted with glass water-gauges and with relief pipes. The method of operation was as follows. The hot-well discharge —which contained the condensed steam passing through the cylinders, the jacket condensation, and also the steam used for

heating the feed water, as well as the other quantities mentioned in the next paragraph—was allowed always to run into one or the other tank, and filled each one up in turn in about 3½ minutes. By means of the lower cock the feed pump was put into connection with the tank into which the hot-well was *not* discharging, and emptied it in about 2½ minutes. For each tankful there was therefore about one spare minute in which to ensure its complete emptiness or fullness and to note the temperatures &c. During this time the feed pump had to be stopped, being started again directly the next tank was full. After the trial the tanks were re-erected with all their connections at University College, London, and water carefully weighed into them. It was found that one held 1,808 lbs. and the other 1,785 lbs. of water at 62° Fahr.; and also that the probable error of the filling and emptying as carried out on the trial was not more than 2 lbs. in each tank, and was equally likely to be *plus* or *minus*. It seems therefore that the method of water measurement used, although very laborious, must have given very closely accurate results. A more elaborate system with storage tanks, which was preferred by the Committee, could not be carried out for want of room on the vessel. The temperature of each tank was taken, so that a very good average value of the feed-water temperature was obtained.

The steam made by the boilers, corresponding with the measured weight of the water, all went to the main engine, except the small quantity required to drive the Worthington pump, which may be fairly considered comparable with the quantity required for the feed pump of an ordinary engine. The circulating pump, the dynamo engine, the winch engines, the steering engines, &c., were all worked from a donkey boiler, which was specially kept going for that purpose. The exhaust from the circulating-pump engine and also that from the dynamo engine were both taken into the condenser, and therefore were measured through the feed tank on their way to the main boilers. These additions to the ordinary air-pump discharge more than made up for the various losses of steam through the engine: so that from time to time part of the hot-well discharge had to be thrown away, and not taken to the main boilers. The whole of the pipe connections between the boilers and engines, which were of

very great complexity, were carefully examined before the trial, to make sure that no unintended communication existed.

Power Measurement.—Indicator diagrams were taken at half-hourly intervals throughout the whole trial. Six Crosby indicators were used, one on each end of each cylinder; the connections in all cases were through only a few inches of large pipe having in no case more than one bend.

The revolutions were noted half-hourly on the counter, all the gauges being read at the same time.

General Conditions.—The general conditions as to speed, power, steam pressure, frequency of stoking, and so on were all those of ordinary working on a southward journey, and were fixed beforehand by the chief engineer.

Results.—The results are shown graphically in Plates 45 and 46, and their principal points are the following:—

Duration of Trial.—The trial, which was made on a voyage from Leith to London, commenced at 1.30 a.m. on Sunday, 24th June, and ended for the engines at 6.36 p.m. and for the boiler at 6.39 p.m. upon the same day. Its duration was therefore 17 hours 6 minutes for the engines, and 17 hours 9 minutes for the boilers. This small difference of three minutes arises from the fact that the signal for ending the engine trial, that is for taking the last reading of the counter, was given three minutes before the water in the boiler gauge-glass reached the level from which it had started. The weather was fair throughout.

Fuel.—The coal used in the after stoke-hole was 16,675 lbs. upon the starboard side and 16,831 lbs. upon the port side. In the forward stoke-hole these amounts were respectively 18,242 lbs. and 16,945 lbs. The starboard boiler therefore used 34,917 lbs., and the port boiler 33,776 lbs. of fuel. The total quantity was 68,693 lbs., or 4,005 lbs. per hour.

At the end of the trial it was found on cleaning the fires that the ash amounted to 1,671 lbs., and the clinker to 2,806 lbs. in addition. The ash was therefore 2·43 per cent. of the total fuel, the clinker 4·08 per cent. of the total fuel, and the two together 6·51 per cent. of the total fuel.

The mean temperature of the escaping gases, deduced from thirty-eight observations, was 791° Fahr. The chimney draft was constantly about 5–16ths of an inch of water. The sample of furnace gases which was brought successfully to analysis gave the following results by volume and by weight:—

Carbonic Acid .	12·5 per cent. by volume, and	18·17 per cent. by weight.
Carbonic Oxide .	0·8 " " "	0·75 " "
Oxygen . .	5·4 " " "	5·71 " "
Nitrogen . .	81·2 " " "	75·37 " "

This sample was collected at 11.30 a.m. under normal conditions of working. During the greater part of the trial the fires were worked very thick, indeed as thick as possible, and they were so at the end of the trial; as already mentioned they were not cleaned during the trial. Very much smoke was always emitted after stoking; but while no stoking was actually going on, there was not much smoke. The times of stoking were noted frequently; and on the average it was found that stoking occurred in each stoke-hole about every 24 minutes, all the fires being stoked one after the other as quickly as possible.

Feed Water.—The mean temperature of the feed water, which was heated before leaving the hot-well by an apparatus devised by Mr. Clephane, the chief engineer of the ship, was 163·1° Fahr.; it was very fairly constant between 160° and 170° during the whole trial. At this temperature the amounts of water contained by the two measuring tanks are 1,771 lbs. and 1,749 lbs. respectively, these figures being found by calculation from those already given. During the trial the larger tank was filled 145 times, and the smaller 146 times. The total quantity of water used was therefore 512,150 lbs., or 29,860 lbs. per hour.

Speed.—The counter read 1,439,668 at 1.30 a.m. when the trial commenced, and 1,513,318 at 6.36 p.m. when the trial ended. The total number of revolutions made by the engines was therefore 73,650, the time being 17 hours 6 minutes, which gives the average rate of 71·78 revolutions per minute. The maximum number of revolutions per minute for any half-hour was 72·4, and the minimum 70·9.

Pressures, &c.—The mean barometric pressure during the trial was 30·34 inches of mercury, or say 14·9 lbs. per square inch. The mean boiler pressure was 145·2 lbs. per square inch. The other pressures were as follows:—

High-pressure jacket	131·0 lbs. per square inch.
Intermediate jacket	77·5 " " " "
Low-pressure jacket	56·8 " " " "
First receiver	36·5 " " " "
Second receiver	6·2 " " " "

All these pressures are given above the atmospheric pressure. They were observed every half-hour throughout the trial. The gauge for the boiler pressure was checked by a standard gauge; the other gauges were not checked, and their readings must therefore be taken as approximate only. The average pressure during admission to the high-pressure cylinder (from measurements of diagrams) was 134·4 lbs. per square inch. The actual initial pressure (or pressure just at the commencement of the stroke) was practically the same as this in the top diagrams, and 6 or 7 lbs. higher in the bottom diagrams. The difference between the average admission pressure and the boiler pressure was thus (assuming the gauge to be correct) 10·8 lbs. per square inch. The mean reading of the vacuum gauge was 24·78 inches of mercury, or 12·17 lbs. per square inch below the atmosphere. The mean vacuum in the low-pressure cylinder (obtained by detailed measurement of all the diagrams) was 11·6 lbs. per square inch below the atmosphere. The absolute back pressure was therefore 2·73 lbs. in the condenser, assuming the gauge to be correct, and 3·3 lbs. in the cylinder.

Power.—The following are the mean effective pressures in the different cylinders in lbs. per square inch :—

Cylinder	Top	Bottom	Mean
High-pressure	60·10	56·82	58·46
Intermediate	20·47	18·54	19·50
Low-pressure	12·22	12·55	12·38

These pressures correspond with the following indicated horse-powers :—

High-pressure cylinder	662
Intermediate cylinder	507
Low-pressure cylinder	825
Total Indicated Horse-Power . .	1,994

These figures are the average from thirty-four sets of diagrams, six diagrams in each set. The maximum indicated horse-power given by any one set was 2,086, taken at 5.15 a.m. with 72·1 revolutions per minute and 147 lbs. boiler pressure. The minimum indicated horse-power given by any one set of diagrams was 1,890, taken at 12·45 p.m. with 70·9 revolutions per minute and 140 lbs. boiler pressure. Each set of diagrams was worked out for the revolutions per minute corresponding with the counter readings for the half-hour in which that set was taken. One set of diagrams—that nearest to the mean —is given in Plate 47.

Boiler Efficiencies.—The rate of combustion in the furnaces was 19·25 lbs. of fuel per square foot of grate surface per hour, or 0·602 lb. per square foot of total heating surface per hour. The evaporation was at the rate of 7·46 lbs. of water per lb. of fuel put on the fire, including clinker. This water, being supplied at a temperature of 163° Fahr. and evaporated at a temperature of 363°, must have received heat at the rate of 1,062 thermal units per pound. Each pound of it was therefore equivalent to 1·10 lb. evaporated from and at 212°. The actual evaporation reduced to this standard was therefore 8·21 lbs. of water per lb. of coal, or about 9·62 lbs. per lb. of carbon-value in fuel, allowing for clinker. The equivalent amount of heat utilised per lb. of coal was 7,922 thermal units, or say 62 per cent. of the whole calorific value of the coal, which

percentage therefore represents the actual boiler efficiency. The total nominal calorific value of the fuel burnt per minute was 853,900 thermal units. Although it cannot be assumed that the analysis of furnace gas already given was a fair average, it has been thought worth while to work it out. It appears from it that the weight of air per pound of carbon was about 22·0 lbs., and per pound of coal about 15·5 lbs. The loss of heat in raising the temperature of the furnace gases works out to 21·9 per cent. of the whole calorific value of the fuel, the loss by formation of carbonic oxide to 3·6 per cent., and that due to the evaporation of the moisture in the fuel to 1·2 per cent. The sample of coal analysed being free from clinker, the 4 per cent. of clinker may roughly be said to correspond to a loss of about 3 per cent. of the whole heat. These quantities add up to 91·7 per cent. of the whole heat of combustion; and the balance must include, among other things, all losses by radiation. The amount of water evaporated per square foot of tube surface was 5·18 lbs. per hour, and per square foot of total heating surface 4·49 lbs. per hour. These quantities have to be multiplied by 1·1 to bring them to standard conditions. The average rate of transmission of heat through the material of the boiler was 5,244 thermal units per square foot of heating surface per hour. (See correction of this number to 4,769 in discussion, pages 257 and 259.)

Engine Efficiencies.—The measurement of feed water shows that the quantity used per indicated horse-power per hour was only 14·98 lbs., or within the limits of accuracy of measurement 15·0 lbs. The actual heat received by the feed water per minute was 528,700 thermal units, or 265·6 thermal units per indicated horse-power per minute, which, as given in the last paragraph, is 62 per cent. of the whole heat of combustion. For purposes of comparison with a perfect engine, it may be assumed that the higher limit of temperature is that of the boiler steam, 363° Fahr., while the lower limit may be taken as 120° Fahr. It was unfortunately impossible to measure the temperature of the condensed steam as it entered the hot-well; but with the good vacuum given above, it is not probable that it differed much from 120° Fahr. (The temperature corresponding to the mean back-pressure in the low-pressure cylinder is 146° Fahr.)

If the engine had been "perfect" and had worked between 363° and 120° Fahr., it should have turned into work 0·295 of the heat received by it. The heat actually turned into work was 85,240 thermal units per minute, showing an efficiency of 54·6 per cent. as compared with a "perfect" engine working between the same limits of temperature and receiving the same quantity of heat per minute. This is a high efficiency, but corresponds with the low feed-water consumption. The absolute engine efficiency, or ratio of the heat turned into work to the total heat received by the feed water, was 16·1 per cent.

Total Efficiency.—The combined efficiency of the boilers and engines, or ratio of the heat turned into work to the total heat of combustion of the fuel, was almost exactly 10·0 per cent.

Steam by Indicator Diagrams.—Careful measurements of all the diagrams taken have been made to ascertain the proportion of steam accounted for by them, and the following are the results, the actual weight of feed water used per revolution having been 6·93 lbs.:—

Proportion of Steam accounted for by indicator diagrams.	Lbs. per Revolution.	Percentage of Total Feed.	Percentage in Jackets or present in cylinder as water.
	Lbs.	Per cent.	Per cent.
Steam present in high-pressure cylinder after cut-off, when the pressure was 110 lbs. per square inch above the atmosphere	5·34	77·1	22·9
Steam present in intermediate cylinder, when the pressure was 22 lbs. per square inch above the atmosphere .	5·56*	80·2	19·8
Steam present in low-pressure cylinder near end of expansion, when the pressure was 4 lbs. per square inch below the atmosphere	5·22	75·3	24·7

It will thus be seen that even in these very economical engines, and with a liberal allowance for the steam used in jackets, which unfortunately could not be separately measured, there must have been a very considerable loss due to cylinder condensation.

In Fig. 8, Plate 48, are shown expansions of the set of indicator diagrams given in Plate 47, each expanded diagram being the mean of the two corresponding actual ones. The full lines in Plate 48 show these mean indicator diagrams themselves drawn to the same scale of pressure and of volume, and placed so that the space to the left of each diagram represents the clearance space in the corresponding cylinder. The dotted lines in Plate 48 show the same diagrams set back (in the manner described in Proceedings 1887, page 70) in such a way that at any pressure the horizontal distance A B measures the actual volume of *working* steam in the cylinder at that pressure, as represented by the difference between the volume of steam of that pressure in the cylinder during expansion and during compression, or A E – A D, independently altogether of clearance steam. Each horizontal distance or abscissa of the dotted curves, such as A B, is therefore directly comparable with the corresponding abscissa A C of the saturation curve S S; and the ratio of the one to the other $\frac{A\,B}{A\,C}$ at any pressure gives the "dryness fraction," or ratio of steam to mixed steam and water, for the working steam at that pressure.

In Fig. 9, Plate 49, the same diagrams are treated in a somewhat different manner, proposed by Professor Unwin. The mean indicator diagrams themselves are here again expanded in the usual fashion, as shown by the full lines. The expansion line of each is continued to the end of the stroke at B, and the horizontal line Q A B is drawn. Then the length A C is set off from the compression line (produced if necessary) to represent the volume of the whole feed-water per stroke (less jacket water, if any), if it were entirely steam of the pressure at B; and a saturation curve is drawn upwards through C. Then at any pressure Q B represents the volume of the whole steam in the cylinder; B C the volume of the steam corresponding with the water in the cylinder, apart from accumulated water if any; while Q A shows the volume of steam in the clearance space when the same pressure is reached in the return stroke. The distance A B therefore represents the volume of working steam, and the ratio $\frac{A\,B}{A\,C}$ the "dryness fraction" in the same way as the similarly lettered distances in Plate 48.

Coal Consumption.—The total coal put on the fires, 4,005 lbs. per hour, corresponds to 2·01 lbs. of coal per indicated horse-power per hour, of the quality already stated. This corresponds to 1·76 lbs. of carbon-value per indicated horse-power per hour, or say 427 thermal units per indicated horse-power per minute. As each indicated horse-power per minute is equivalent to only 42·75 thermal units, this makes the combined efficiency of boilers and engines 10·0 per cent., as given above.

Speed of Vessel.—The following notes from the log book of the ship may be of interest:—

	Time.	Distance in nautical miles.
Left Leith Pier Head . . .	0·50 a.m.	0
Bass Rock	2·20	20
St. Abb's Head	3·40	39½
Farn Isles Lighthouse . .	5·10	62
Flamborough Head . . .	0·50 p.m.	175
Dudgeon Floating Light . .	4·57	236
Cromer	6·25	257
Haseborough	7·0	265½
Cockle	7·46	275

The mean speed between Leith and Cromer, which practically covers the trial, was therefore 14·6 knots.

Supplementary Trial.—Some hours after the main trial was finished, and after all the fires had been cleaned, the stoke-hole was closed, the fans set to work, and the engine driven for a few hours at full power with forced draught. The particulars of the work done under these circumstances are given in Table 1 on the next page. As to diagrams C, E, and F, which were taken with live steam admitted to the first receiver, it may be explained that the engine has an auxiliary starting valve of 2½ inches diameter, which enables this to be done. This valve is occasionally used when there is any fear of the boiler blowing off, so as to avoid waste of steam and fresh water. This occurs generally for only a minute or two at a time. The engines run from 2 to 3 and sometimes as much as 4 revolutions per minute faster, and it will be seen that the diagrams shown in Plates 51 and 53 are much distorted, and the pressure on the intermediate piston much increased.

TABLE 1.—*Supplementary Trial at full power with forced draught.*

Indicator Diagrams.	Boiler Pressure per sq. inch above atm.	Revolutions per minute.	Mean Pressure per square inch.			Indicated Horse-power.			
			High-pressure cylinder.	Intermediate cylinder.	Low-pressure cylinder.	High-pressure cylinder.	Intermediate cylinder.	Low-pressure cylinder.	Total.
Set.	Lbs.	Revs.	Lbs.	Lbs.	Lbs.	I.H.P.	I.H.P.	I.H.P.	I.H.P.
A	146	81·0	60·9	28·4	18·5	778	832	1393	3003
B	151	81·0	63·2	28·8	19·0	808	844	1126	3078
C	150	83·4	30·2	33·7	21·1	397	1013	1863	3273
D	145	78·7	61·1	25·5	16·7	796	727	1222	2745
E	136	80·0	32·9	33·0	21·8	415	957	1617	2989
F	130	80·0	31·2	32·9	21·6	394	952	1608	2954

The four sets of diagrams A C D F are shown in Plates 6 to 9.

Diagrams A (Plate 50) and B are believed to represent the average full-power working of the engines going north from London to Leith, when the steamer always runs with forced draft. Diagrams C (Plate 51) correspond to the conditions of A and B, but with live steam admitted to the first receiver.

Diagrams D (Plate 52) are believed to represent the average working of the engines later on in the same full-power run when the tubes are getting dirty, the high-pressure motion being drawn up about 1 inch. Diagrams E and F (Plate 53) correspond to the conditions of D, but with live steam admitted to the first receiver.

When the vessel got into port and was being berthed, it was endeavoured to get a set of indicator diagrams while the engines were going astern. One complete set only was secured, Plate 54, of which the following are the particulars, all the links being in full gear :—

Boiler pressure, lbs. per sq. inch above atm. .	lbs.	147
Revolutions per minute	revs.	76
Vacuum in inches of mercury	ins.	27
Mean pressure, high-pressure cylinder . .	lbs.	48·8
,, ,, intermediate cylinder . .	lbs.	31·5
,, ,, low-pressure cylinder . .	lbs.	17·1
Indicated Horse-Power, high-pressure cylinder	I.H.P.	585
,, ,, intermediate cylinder	I.H.P.	867
,, ,, low-pressure cylinder	I.H.P.	1,208
,, ,, Total . . .	I.H.P.	2,660

It is interesting to compare the results thus obtained with those when running in forward gear (page 243 and Plate 47), as showing the effect of altering the sequence of the cranks, which under these circumstances follow in the order—high, low, intermediate.

Observers.—As this trial was perhaps the first marine-engine trial carried out on any large scale at sea in which the feed water was measured and the coal weighed throughout for such a length of time, it may be interesting to mention the staff which was found necessary for the experiments. The work was carried on by two relays of observers, five in each relay, keeping alternate four-hour watches. Mr. Frederick Edwards took charge of one watch, consisting of Mr. Bryan Donkin, Jun., Mr. A. G. Ashcroft, Professor Beare, Mr. Beck, and himself. The writer took charge of the other watch, on which were also Mr. C. L. Simpson, Mr. R. H. Willis, Mr. B. Bramwell, and Mr. N. Burnett. One man in each watch took the feed-water measurements continuously; with him was an engineer, specially engaged for the purpose, to stop and start the feed pump as the tanks were changed in the manner above described. Two observers in each watch took the indicator diagrams and other observations in the engine-room; and two others attended to the coal measurements,

one in each stoke-hole; these four interchanged places after every two hours' work. As it was necessary that the ordinary work of the ship should not be interfered with, or the time of the engineer's staff encroached upon, an extra stoker was carried in each stoke-hole for the purpose of filling the coal baskets to be weighed. An extra man was also carried to look after the donkey boiler, which for reasons already mentioned had to be kept going during the whole trip. Besides the ten observers already mentioned, there were thus seven others employed, allowing for change of watch. The whole trial, although requiring very close and continuous attention on the part of those engaged on it, went off without the least hitch of any kind, a fact which was no doubt due in a great extent to the very cordial help received throughout from everybody connected with the ship, but especially from Mr. Clephane, the chief engineer; his co-operation throughout was invaluable, and the Committee have much pleasure in taking this opportunity of acknowledging it. They are also indebted to Messrs. J. and G. Thomson, who have kindly furnished them with detail drawings of the cylinders and other parts of the engines; to Mr. C. J. Wilson, F.C.S., for analysing the furnace-gases and the coal; and of course in the highest degree to Mr. Aitken, of the London and Edinburgh Shipping Company, for his kindness in allowing the trial to be made, and for the trouble which he took in connection therewith.

Discussion.

The President said that, as the Report just read was the first which the Institution had received from their Research Committee on Marine-Engine Trials, the Members would naturally be interested in knowing the names of the gentlemen constituting this Committee, who were the twenty following:—Professor Alexander B. W. Kennedy, F.R.S., Chairman; Mr. William Anderson; Mr. Walter Brock; Mr. Horace Darwin; Mr. Bryan Donkin, Jun.; Mr. John Dunlop; Mr. Frederick Edwards; Mr. R. Edmund Froude; Mr. Alexander C. Kirk, LL.D.; Mr. John List; Mr. Michael Longridge; Mr. John G. Mair; Mr. William H. Maw; Mr. William Parker; (the late) Sir William Pearce, Bart., M.P.; Mr. A. E. Seaton; Mr. Richard Sennett; Mr. Archibald Thomson; Professor W. Cawthorne Unwin, F.R.S.; and Mr. W. H. White, F.R.S.

Professor Kennedy, Member of Council, was glad the President had given the names of the Committee, because, without in the slightest degree desiring to lessen any personal responsibility of his own with reference to the trial or the report, he wished to say that, although the carrying out of the trial had not been done by the Committee as a body, their work had been by no means of a purely nominal kind. They had discussed in great detail at repeated meetings all the methods to be employed in trials of this kind; and the credit of the success of these methods was practically due to the Committee as a body. From the names of the Committee it would be noticed that they were thoroughly competent to deal with the matters brought before them.

With regard to the exact diameters of the cylinders (page 235), it had not been possible to measure these before the calculations were worked out; but the alteration due to the subsequent accurate measurement was only one-fifth of one per cent., raising the indicated horse-power on page 243 to 1,998 instead of 1,994.

About the method of starting and ending the experiment he had been asked some questions, as it had not been described in the

(Professor Kennedy.)
report. What it had been endeavoured to do was to obtain as far as could be fires of about the same value at the beginning and at the end of the trial. Of course it was impossible to judge the amount of coal upon the grate correctly enough to get it the same at the end as at the beginning. As a matter of fact it could not be the same, because it had been decided not to clean the fires during the trial. There was a ton of clinker got out at the end of the trial; a great portion of this must have been in the fires at the end, and certainly they were much thicker then than at the beginning. The endeavour had been to have the engines running as nearly as could be at the same speed, and under normal conditions, at the beginning and at the end. The fires were let alone just before the beginning of the trial until they would not keep up the steam, so that, as seen in Fig. 4, Plate 46, the pressure fell from 151 lbs. down to 143; and the experiment was then commenced by firing with weighed coal. The same conditions existed at the end of the trial, the fires being left alone until they would no longer keep up the steam pressure. Thus both at the beginning and at the end the value of the fires was such as would just not keep up the steam. Of course in such a long trial there was not likely to be any considerable error from inequality of fires at start and at finish; but probably this was the most accurate way in which the matter could be dealt with. The idea of drawing the fires was altogether out of the question.

Since the "Meteor" trial now reported upon, another trial had been made by the Committee on a smaller boat, the "Fusiyama," having ordinary two-cylinder compound engines which had recently been overhauled. The principal results of the later trial would form the subject of another report now in course of preparation. The engines were working with about 58 lbs. pressure of steam, and exerting 371 indicated horse-power; the consumption was found to be 2·68 lbs. of coal per indicated horse-power per hour, and the evaporation was 8·1 lbs. of water per lb. of coal at the pressure of 58 lbs., which was equivalent to an evaporation of 9 lbs. of water from and at 212°, corresponding with the use of 21·7 lbs. of water per indicated horse-power per hour. Through the kindness of Mr. Holden and Mr. Seaton, who had used their influence with

the Great Eastern Railway, he was happy to say it had been arranged to have a trial of their new vessel, the "Colchester," running between Harwich and Antwerp, which probably represented the very best that could now be done in compound engines of such a size. She was a twin-screw vessel indicating about 2,000 horse-power, and her engines were not triple-expansion but two-cylinder compound, and had been built at the beginning of the present year, so that they represented the latest improvements in two-cylinder compound engines; and the results would be correspondingly interesting.

It was only fair to the Committee to point out that the object of these trials was not to form a basis on which to criticise the design of the engines or anything of that kind. The object was two-fold:— firstly to find out what a particular set of fairly representative engines were actually doing; and secondly to see whether this could be ascertained under conditions which did not interfere with the ordinary working of the engines. No attempt therefore was made to discover what setting of the valves and valve-gear would make the engines work in the most economical fashion; or whether the engines might or might not have worked better if the cut-off had been different, or if the proportions of the cylinders had been altered. These were not matters with which the Committee had to deal, although naturally they were matters of which the interest was obvious to everybody. What it was wished to ascertain was whether the actual working of any marine engines could be accurately and scientifically measured, without in any way interfering with their ordinary working. In the trials already made it had been found that this could really be accomplished; there had been no interference with the ordinary working of the engines.

Mr. W. H. White, as one of the members of the Committee, could speak with perfect impartiality of their work, because to his regret he had been unable to do anything to help it forward; this however had not been for want of will, but absolutely for want of opportunity and time. With the objects aimed at in the enquiry he had the liveliest sympathy; and he thought it was impossible to

(Mr. W. H. White.)

exaggerate the importance of the results already obtained. As a beginning in a new field of research it was certainly a commencement of which the Institution might be proud. Professor Kennedy had spoken, as became him as Chairman, of the value of the assistance he had received from the members of the Committee; but whatever might be the result of the Committee's deliberations, the work done should be considered as largely and practically that of Professor Kennedy himself. It was perfectly true that methods of enquiry might be discussed and arranged in committee; and there could be no doubt that such a committee as had been constituted would be sure to make valuable suggestions as to methods of procedure. But when it came to the actual work of conducting an experiment of this nature, he thought Professor Kennedy's remarks had not conveyed much of what was really involved in carrying out observations which had resulted in such a valuable collection of facts. What had to be discovered first of all were the facts of the case. In the problem of steamship propulsion, as ordinarily treated, a great many diverse elements were rolled together, and in practice it was only with the concrete result that engineers were usually concerned. But when the problem was brought before an Institution like this, it was necessary not merely to deal with the result in the aggregate, but also most carefully to collate and analyse all the several sections of the result; otherwise it was impossible to make any proper progress. Knowing something himself of what was involved in making experiments, one feature in the report which commended itself to him was the extreme frankness with which Professor Kennedy on behalf of the Committee had drawn attention to the want of completeness in certain portions of the enquiry. The report did not profess to be a perfect investigation of the questions involved; and there were certain points in regard to which, if the omissions that had necessarily occurred in the enquiry could have been filled up, the results would have been even more valuable than they were. It would be possible for example, if he was not mistaken, to improve upon what had been done (page 239) in regard to the exhaust from the circulating-pump engine and also that from the dynamo engine, both of which were taken into the condenser,

and therefore were measured through the feed tank on their way to the boiler. He did not know whether in the feed-water measurement any deduction had been made for that additional water.

Professor Kennedy explained that all the water which passed through the tanks and was measured went to the main boilers, although a portion of it had originally been steam in the donkey boiler. So there was no deduction to be made on this score.

Mr. White said it seemed from the report as if that was a point where a necessary deduction would have to be made. Then again, as frankly stated on page 245, the quantity of the steam used in the jackets could not be separately measured. This was a most important point, and it would no doubt be a great advantage if in any subsequent investigations it could be dealt with in a quantitative fashion. But the main results recorded in the report appeared to be not merely of great value and importance in themselves, but likely to lead to a more exact appraisement of the efficiency of the propelling apparatus of steamships than had ever been made before. The ship-owning and ship-building communities he was sure would feel under the greatest obligation to the Institution for the enquiry which had been undertaken and so far carried out.

Mr. Andrew Brown, of Messrs. William Simons and Co., Renfrew, mentioned that about 1851 or 1852 he happened to be engaged upon the engines of the "Prompt," the first screw steamer of the Edinburgh and Leith Shipping Company; they were a pair of beam jet-condensing engines, with cogwheel gearing driving the propeller. The vessel was rather a novelty at that time, and was looked upon as a bold venture, the company's over-sea carriage having previously been effected by sailing smacks. The boiler pressure was 15 lbs., and the consumption of fuel was about 8 or 10 lbs. per horse-power per hour, which of course could not be compared with the present consumption of only 2 lbs. in triple-expansion

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engines working with steam at 160 lbs. There was another steamer, the "Malvena," built at the same time by Messrs. Napier, and having the same kind of engines. The two boats took their maiden trips from the Clyde to London. Looking back to that time, the progress since made was something wonderful. The experiments described in the report were of great value; and shipowners, shipbuilders, and engineers would all alike be highly interested in them.

Mr. EDWARD H. CARBUTT, Past-President, said that when he was President of the Institution he had had the pleasure of attending ex officio the meetings of the Committee who had this question in hand. Every detail had been thoroughly discussed by that Committee. Professor Kennedy of course led the way as chairman, but took great care that every member of the Committee should express his opinion as to the best mode of conducting the trials. He could himself only express his delight that the trials had been carried out so satisfactorily; and he thought that the Institution was greatly indebted to Professor Kennedy for having thrown so much spirit into the work, and for having persuaded other members of the Committee to go with him and conduct the trials. No doubt the trials had not been as perfect as they would like them to have been; but one result of the report would be that Members like Mr. White, who could be of such great service in the matter, might be induced in future to give a little of their time to it, so that by their aid more perfect experiments might be made which would add to the value of those already carried out. The Institution was determined that a large portion of the money it had saved should be spent in these experimental researches; and if only Members who had the ability could be persuaded to tell them what was the best way of carrying out the experiments, the Council would so carry them out, in order that the results might be of some service to the shipbuilders and marine engineers of the country.

Mr. THOMAS AITKEN, responding to the President's invitation to speak on the subject, expressed the very great pleasure he had had in giving all the facilities in his power for conducting the experiments

on board the "Meteor." The comparison between the early experiments referred to by Mr. Brown and those recently carried out on the "Meteor" would show that a great deal had been done in the way of improvement.

The President called attention to the rate of transmission of heat through the boiler plates (page 244). So far as he was able at present to make out from the report he imagined that the average rate of transmission of heat through the material of the boiler was $7{,}922 \times 0\cdot602 = 4{,}769$ thermal units per square foot of heating surface per hour, instead of 5,244. No doubt Professor Kennedy would soon put this right.

The next point to which he wished to call attention, in the hope that it might lead to discussion, was (page 245) the proportion of steam accounted for by the indicator diagrams. It could not have failed to attract attention that there was a great difference between the quantity of steam represented in the three cylinders, although presumably the same quantity was passing through each. The percentage of total feed present as steam in the high-pressure cylinder was given at 77·1 per cent., with a deficit of 22·9. The percentage in the intermediate cylinder was higher, namely 80·2, with a loss of only 19·8. But on coming to the low-pressure cylinder there was a fall of steam to 75·3 per cent., with 24·7 loss. On looking at the diagrams in Plate 47, it would be found that in the high-pressure cylinder, Fig. 5, the point of measurement of the steam which was stated to have been adopted, namely at 110 lbs. pressure above atmosphere, corresponded with about 57 per cent. of the length of the stroke, taking the mean of the two diagrams from the bottom and top ends of the high-pressure cylinder. It had puzzled him to understand how it was that the measurement could then give more steam in the second cylinder than there had been in the first. But it would be seen that for some reason or other the measurement in the intermediate cylinder, Fig. 6, being taken at 22 lbs. above atmosphere, corresponded with no less a distance than about 82 per cent. of the stroke. And similarly in the low-pressure cylinder, Fig. 7, it would be seen that the volume of steam had been

(The President.)
measured at about the same percentage of the length of the stroke. No doubt there had been some good reason for making the measurements at those different percentages of the stroke. It was puzzling to know how far, in travelling out of the high-pressure cylinder into the intermediate cylinder, and measuring in the latter at a greater length of the stroke, re-evaporation had taken place so as to give more steam in the intermediate cylinder; and there was also the puzzle as to why the same result had not been shown in the low-pressure cylinder, and why the steam should here have fallen again to 75·3 per cent., after the intermediate cylinder had shown a marked excess of steam at the point at which the measurement was taken.

Professor KENNEDY, having been asked some questions as to how the feed water tanks had been arranged for carrying out the measurements, explained that there were a pair of tanks, which were connected at the bottom with one two-way cock and at the top with another. One branch of the upper cock communicated always with the hot-well. Supposing this cock were also open to the right-hand tank, the feed water would be flowing into that tank and filling it, while at the same time the water was running out of the left-hand tank through the bottom cock to the feed pump. Either tank would empty more quickly than the other tank filled. This was of course a necessity of the case, or else the arrangement could not be worked; in other words, the feed pump must have power enough to draw more quickly than the discharge from the hot-well was delivered. As soon as the left or emptying tank was quite emptied, the bottom cock was simply turned into such a position as to shut off its communication to the feed pump. The boiler was then for a short interval receiving no water, while the right-hand or filling tank was filling up full to the top; and the only point where there seemed a possibility of error was in filling up each tank in turn exactly to the correct height. But it was easy so to contrive the shape of the tanks at the top that the error should be extremely small; and as mentioned in the report (page 239) he had measured the error after the trial by re-erecting the tanks in his

laboratory, and had found it to be quite negligible. All error might indeed be avoided by connecting together the air-pipes or relief-pipes on the top of the tanks by a cross horizontal pipe at the level of the centre of the upper cock; so that, if ever the upper cock was not reversed quite in time when the filling tank was filled full, the only consequence would be that some of the water from the full tank would prematurely run over into the empty tank, and therefore the full tank could not be filled above the intended level. If the upper cock were then reversed, the water from the hot-well would commence to run into the empty tank; and the bottom cock could at the same time be opened to the full tank, so as to allow the feed pump to empty it. This arrangement did with two cocks only, which was a very important point when the manipulations had to be made so frequently, and under circumstances that were not the most favourable for making rapid manipulations. Of course it would be better to have, as the Committee had originally proposed, a more elaborate arrangement which, by the use of reserve or reservoir tanks, should leave an interval of five or ten minutes free; but such an arrangement it was not always possible to get in the confined space on board a steamer.

With regard to the rate of transmission of heat through the material of the boiler (page 244), the number given by the President, namely 4,769 thermal units per square foot of heating surface per hour, was correct. The number 5,244 was due to the multiplication by 1·1 having accidentally been made twice over.

The principle on which the measurements of steam had been made from the indicator diagrams in Plate 47 was simply that in the high-pressure cylinder the measurement was made as soon as possible after the cut-off, and in the two other cylinders as late as possible before exhausting. It would of course have been better also to measure directly after the cut-off in the two other cylinders, but in these the point of cut-off was not so well defined as in the high-pressure cylinder; in fact it was not really well defined in any of the three. It would therefore have been better also to measure as late as possible in the high-pressure cylinder, in order to compare with the other two.

The PRESIDENT asked whether the effect of measuring at such a late period in the second and third cylinders was to allow a certain amount of water to re-evaporate into steam, and so to give a larger measurement of steam than would be obtained at an earlier period of the stroke.

Professor KENNEDY had no doubt there had been re-evaporation, but he should not like to say how much, without having measured the diagrams with that object. Each diagram had been measured in one place only, because the operation of measurement was so very laborious.

Mr. P. W. WILLANS said the results of these trials had been looked forward to by engineers with great interest and anxiety, in order that they might know what large marine engines were really doing; and after the labours of Professor Kennedy and the other gentlemen who were associated with him as observers, he thought there was no doubt that they did now know within very narrow limits indeed what these particular engines were actually doing. There were however one or two unfortunate omissions, which he had no doubt Professor Kennedy would be able to explain. One was that the jacket water had not been measured; and therefore in the Table in page 245, to which the President had referred, and in which from 19·8 to 24·7 per cent. of the feed water was shown to be missing as steam, the jacket water was included with the water present in the cylinder. It was very important to know what the initial condensation was in such large cylinders; and this information could not be got from the data recorded. It was to be hoped that, if any more trials of this kind were made, these figures would be ascertained at whatever cost, because the matter was one of the utmost importance. It seemed evident however that the initial condensation was large, as inferred in the report, for the object of jackets was to diminish initial condensation; and assuming that any large proportion of the 22·9 per cent. pertaining to the high-pressure cylinder was condensed in the jackets, it was evident that in an engine which was not jacketed still more initial condensation would take place.

As to the main result, it certainly seemed to him that the water consumption in the engine was large (page 244). Although 15 lbs. of feed water per indicated horse-power per hour seemed low in comparison with earlier experience, yet it must be borne in mind that these engines were working with a high initial pressure of steam and with a moderate range of temperature in each cylinder. It certainly seemed to him therefore that some recent performances of marine engines could not have been quite as good as they were said to be, seeing that the present trial, which had been so carefully made, gave as much as 15 lbs. of water.

The report had gone fully into the efficiency of the engines and boilers, and it had been pointed out (page 245) that their combined efficiency amounted to only about 10 per cent.; that is, only about 10 per cent. of the total heat in the fuel was turned into useful work. This seemed a bad result; but he thought it was not desirable to look at the efficiency from the point of view of absolute perfection, because the physical conditions would account for nearly the whole of the deficient 90 per cent., and there was no hope that any steam engine or heat engine would give back in the shape of useful work any large part of the heat supplied. About the boiler he did not intend to say anything, but would deal merely with the separate efficiency of the engine, which in page 245 was made out to be about 54 per cent. But the engine he thought was really doing better than this, when the comparison was made with what such an engine was actually capable of doing. First of all however it would appear as though the engine was doing a little worse than represented in the report, in which it was compared with an ideal engine following the Carnot cycle and working between the temperatures of 363° and 120° Fahr. The heat supplied per minute to the feed water was given as 528,700 units, of which 85,240 were actually turned into work in the cylinders, showing an absolute efficiency of 16·1 per cent. But it appeared from page 241 that the 528,700 heat-units were supplied to the feed water after it had already acquired from other sources a temperature of 160°; whereas in the Carnot cycle with which the comparison of efficiency was made the

(Mr. P. W. Willans.)
temperature ranged down to 120°. If these figures were correct, and if the heat necessary to raise the temperature of the feed water from 120° to 160° were added, the absolute efficiency would be only about 14 per cent. instead of 16 per cent., and the efficiency according to the Carnot cycle would be only 52·4 per cent. instead of 54·6 per cent.; in this aspect therefore the engine seemed not quite as good as the report made it out to be. Then it had also been stated (page 245) that, if the engine had been "perfect" and had worked between 363° and 120°, it should have turned into work 0·295 of the heat received by it. Now the ideal engine with which it was here compared was not really a steam engine at all, but an engine which received all its heat at the higher temperature. The ordinary steam engine received a good deal of heat between the temperature of the feed and the temperature of the boiler; and it was unreasonable to expect from the heat so received the efficiency of what was here called the perfect engine. It was just as unreasonable as it would be to compare the work done by two hydraulic engines, both receiving the same quantity of water and both exhausting it at the same level, but one of them supplied from a higher level than the other, and working therefore under a higher pressure. The value of heat was determined not only by the number of thermal units supplied, but also by the temperature at which they were supplied. Therefore the only fair comparison to make, as it seemed to him, was with an engine receiving the same amount of heat and receiving it at the same temperature; and this was equivalent to comparing the indicator diagrams for each lb. of steam taken in by each engine and expanded adiabatically from the higher temperature to the lower, and exhausted at the lower temperature. This he thought was also the common-sense way in which practical engineers should look at the efficiency: that is to say, comparing the actual indicator diagram with a perfect indicator diagram from an ideal engine, in which there was supposed to be no initial condensation and no loss between the cylinders; and thus comparing the actual engine with an engine like itself, instead of with an engine that was not like itself. For such a standard engine the formula given by Clausius and other writers on the subject was:—

$$U=(1438-0\cdot7\ A)\frac{A-B}{A}+A-B-B\log_{\epsilon}\frac{A}{B} \quad *$$

where U denoted the heat-units thermodynamically due in the shape of work per lb. weight of steam, and A and B were the temperatures of the initial and exhaust steam respectively, both reckoned from the zero of absolute cold. This formula had also been given approximately by Mr. Macfarlane Gray in the following modified form, with the same signification for the symbols :—

$$U=\left(\frac{1438-0\cdot7\ A}{A}+\frac{A-B}{A+B}\right)(A-B) \quad *$$

Applying either of these formulæ to a standard engine receiving heat as those of the "Meteor" did, but making a perfect use of it, the efficiency of the "Meteor" engines would be 58 per cent., instead of either 52·4 per cent. as he had previously calculated after allowing for the temperature of the feed water, or 54·6 per cent. as given in the report. Yet further, with reference to the temperatures of 363° and 120° which had been taken for calculating the efficiency, he did not see why 120° had been used as the lower temperature. In the case of a non-condensing engine it was not the temperature of the atmosphere or the temperature of the feed water that would be taken as the lower temperature, but the temperature corresponding with the back pressure of the atmosphere on the day of the trial. So with a condensing engine it was the temperature answering to the back pressure in the condenser that should be taken as the lower temperature, which would be about 140°. This seemed the common-sense view of the matter, because the feed water could always be heated up to that temperature, theoretically at any rate, inasmuch as the exhaust steam itself could be used to heat the feed water up to nearly its own temperature. In comparison therefore with such an engine the "Meteor" engines had done 64·3 per cent. of what they could possibly be expected to do, instead of only the 54·6 per cent. given in the report. Their performance was thus about a fifth better, and they ought to have the credit for it. The next question was why had they not

* Proceedings of the Institution of Civil Engineers, vol. xciii, 1888, pages 191 and 131.

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done better still: because 64 per cent. did not seem a great deal to do, being only two-thirds of what was theoretically possible, although in the report they were spoken of as economical engines, and in comparison with ordinary marine engines they might be so. On this point he was obliged to refer to what he had done himself, because he did not happen to have any other experiments with such a range of temperature for comparison. A year ago he had made some trials with an engine working between almost the same limits of temperature, 370° and 158° Fahr., being a range of 212° in the temperature of the steam. The consumption of water per indicated horse-power was 15·2 lbs. per hour, as against 15 lbs.; and the efficiency 67 per cent., as against 64 per cent. Perhaps it was not strictly fair to compare the engines, because his own engine stood on a space only two feet square and was only 40 horse-power, while the "Meteor" engines were 2,000 horse-power. From the indicator diagrams of the "Meteor" engines in Plate 47 it appeared that in the high-pressure cylinder there was a range of about 80° in temperature, in the intermediate about 61°, and in the low-pressure about 95°. These three ranges added together amounted to about 236°, or about 13° above the total range of 223° from 363° down to 140°; consequently the temperature in each cylinder really overlapped that in the next. In the smaller engine with which he had made his own trials—a non-condensing engine to which a condenser had been added, and which was therefore not specially adapted for the purpose—the ranges of temperature were in the high-pressure cylinder 53°, in the intermediate 48°, and in the low-pressure when it had the condenser attached 86°; the sum of these was only 187°, or 25° less than the total range of 212°. This he thought had something to do with the better result. If the "Meteor" engines had always gone astern, he suggested that the overlapping in the cylinder temperatures would not have been so marked. The indicator diagrams when going astern were flatter at the bottom, Plate 54; this was of course a question of the size of the receiver, and of the order in which the cranks followed. In his own engine, where with a total range of 212° there was an aggregate range in the cylinders of 25° less, the improvement was due in part to the

fact of its being a single-acting engine, and in part to the arrangement of receivers. In compound engines the ranges of the cylinder temperatures ought not to overlap at all; if they did, the engine could not be regarded as really a compound engine; it was not completely compounded unless there was a clear separation between the temperatures in the two cylinders.

With reference to initial condensation, in the case of the "Meteor" jacketed engine the difference between the quantity of steam measured in the high-pressure cylinder and the total steam used (page 245) was 22·9 per cent., which went partly in the jacket and partly in initial condensation. In his own smaller engine, which was not jacketed, the corresponding quantity was only 8·8 per cent. The real explanation he thought was that in his engine the temperatures were better divided, and that the speed was 400 revolutions per minute, whereas the "Meteor" speed was only 80. It was to high speed that it was necessary to turn, if initial condensation was to be eliminated.

With regard to economy in large engines, his view had always been that beyond a certain limit large engines would not be more economical than small ones. Up to a certain point there was a gain in economy, but probably beyond 500 horse-power there would not be much gain. Before long no doubt there would be engines working with 13 lbs. of feed water or less per indicated horse-power per hour; and this result he thought would be attained by engines of 500 horse-power.

Mr. J. Macfarlane Gray heartily concurred in all that had been said regarding the value of the work done by the Research Committee, and especially by Professor Kennedy in drawing up this report. The reports of the Research Committees of the Institution would play an important part in the education of engineers, and in all books on the steam engine they would be frequently quoted as standards of reference, in respect both to facts and to methods of treatment of facts in making comparisons. It was therefore to be regretted, he thought, that the present report, in defining the efficiency of the perfect engine, had departed from the sound

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principle laid down by Rankine and Clausius. In page 245 it was stated that, if the engine had been "perfect" and had worked between 363° and 120° Fahr., it should have turned into work 0·295 of the heat received by it. But he claimed for the engine that, if the reduction of temperature were due solely to the performance of work, and if all the heat which disappeared in that reduction were converted into work, then would it be a perfect engine; that was what Rankine and Clausius had defined the duty of a perfect steam engine to be. According to this view the duty under the conditions named in the report was only 0·266 of the heat expended on the engine; and the efficiency was therefore really 60·6 per cent. of perfection, instead of only 54·6 per cent. as given in the report. No one knew this better than Professor Kennedy; and probably the reason why he had adopted the Carnot function for expressing the efficiency was merely because it was slightly simpler arithmetically. In such reports however he considered it was important to put forward, not that which was most easily calculated, but that which best expressed the true relation of the facts. Any practical engineer had made an important step in understanding thermodynamics when he had clearly grasped what was the difference between the two expressions now put forward for the efficiency of the perfect engine. The Carnot function applied to every element of a heat diagram separately, each for its own range of temperature. When it was applied to the diagram as a whole, the mean range of temperature must be taken, and not the maximum range as in this report. The importance of adhering to the accurate facts of the case was obvious when it was considered that between the accurate efficiency and the approximation adopted there was no fixed ratio. Supposing a Davey motor were working between 219° and 139° Fahr., and a Perkins engine were working between 467° and 139°; then, according to the method adopted in the report, the efficiency of the Perkins engine if perfect would be as much as 3 times that of the Davey motor if perfect; whereas according to Rankine and Clausius the duty of the perfect Perkins engine would be only $2\frac{3}{4}$ times that of the perfect Davey motor; at the lower temperatures of 219° and 139° the relative difference of the two methods was only 3·73 per cent.,

whereas at the higher temperatures of 467° and 139° the relative difference was 9 per cent. The approximation adopted in the report could not therefore be recommended as a legitimate standard of comparison.

Mr. John List, as a member of the Committee, said the trial that had been carried out by Professor Kennedy and other members of the Committee was the first real trial at sea which had been made, and was therefore very valuable. However much might be known about water per indicated horse-power in land engines, nothing had hitherto been known about water per indicated horse-power at sea; and therefore the report was of great value. It would have been more interesting however if the jacket water could have been measured; but having himself been on board the "Meteor" he had seen the difficulties that had to be encountered in carrying out the measurements, and he was sure the omission to measure the jacket water was unavoidable under the circumstances, because the trials had to be carried out while the steamer was doing her regular work, which was a very different matter from making experiments on a trial trip. If they could have a ship to do as they liked with, taking their time, and making such alterations as were desired, the trials might be easy enough; but to carry out the experiments, as had been done in the present case, without interfering at all with the work of the steamer, was really a very different thing, and it reflected great credit on those who had so carried them out.

From the jacket pressures given in page 242 he observed that the high-pressure cylinder was jacketed with steam at 131 lbs. pressure, the intermediate at 77, and the low-pressure at 56 lbs. The last seemed rather a high pressure to use in the low-pressure jacket, rather higher he thought than was really necessary; in general practice he believed it was more usual to jacket the low-pressure cylinder with not more than 10 lbs. above the initial pressure in that cylinder. It would be interesting if it were possible to make trials on board other steamers with engines not fitted with jackets at all; for he had found that marine-engine builders were very

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unwilling to provide jackets now-a-days. Whether it was a matter of first cost or not, he was not prepared to say; but he knew that they objected greatly when jackets were specified, and there seemed to be an opinion amongst some marine engineers of considerable eminence that jackets were superfluous. If therefore trials could be made on engines which were thoroughly jacketed and on engines which were not jacketed at all, or better still on the same engines but with the jackets not in operation, these would help to settle a point that much required settling. From reasons of low first-cost, or of the risk of the jackets not being properly attended to, it might in some cases be advantageous to have none; but his own experience was that where the maximum work was wanted out of an engine it was necessary not only to have jackets but to have them efficiently drained; and he had found the best plan was to make them automatic in draining. If the jackets were left to be drained by some one attending to them, they might be full of water generally; but by adopting simple automatic traps he had found that the jackets worked practically without any attention. By fitting a pipe on the jacket of the first cylinder so as to return the water by gravitation to the boiler, and by fitting separate reducing valves on the jackets of the two other cylinders, with an automatic trap to each jacket, it was possible to render the jackets entirely automatic as regarded steam supply and draining. Another point was to see that the jackets were really tight, in which respect they were often defective; and unless they were carefully fitted there was a considerable loss. It would also be interesting if possible to test an engine fitted with a feed-heater having the water heated by steam taken from the second receiver, as was now extensively done: in order to find what the difference in economy really was between an engine with and without such an arrangement.

The result arrived at in the report as regarded coal consumption per indicated horse-power per hour was practically the same as the results he had obtained with well designed triple-expansion engines using the same class of coal. His own trials had been of considerable duration, the indicator diagrams had been carefully taken, and the coal carefully measured; and the result came out very much the

same, proving therefore that this was the best that could be done with that class of coal and with an average good triple-expansion engine and boiler.

In regard to the statement in page 236 that the "Meteor" engines were fitted with double piston-valves on the second and third cylinders, he was inclined to think the engines would have been more economical if they had been fitted with slide-valves.

Mr. Daniel Adamson, Vice-President, said that, as the President had been kind enough in his opening address (page 218) to characterise as bold some efforts of his in introducing four cylinders to supersede three cylinders, he might explain that as early as 1860 he had engaged to make triple-cylinder engines to drive about 700 horse-power, and had carried them out practically and put them to work early in 1862. Subsequently in 1872 he had made a quadruple engine, and had read a paper on the subject which had been discussed at the meeting of the Iron and Steel Institute at Manchester in September 1875, and in London in November of the same year. As far as the present report was concerned, he certainly felt that he ought to compliment the Chairman of the Committee and the rest of the members upon their great accuracy and care in the records. It appeared they had not taken into consideration whether the engine was a good one, or whether its valves were accurately working, or other particulars of that kind; and after having himself seen so many indicator diagrams taken from compound, triple, and quadruple engines, he had come to the conclusion that those now shown proved that they had been taken from a moderate engine only. The boiler appeared to be of ordinary marine type and of fair proportions, and to be doing a moderate amount of work in proportion to its power and to the area of its fire-grate; but it was not doing work commensurate with the high steam-pressure of 145 lbs. per square inch above the atmosphere. In his own daily practice he managed to get quite as much power per square foot of fire-grate from compound two-cylinder engines working at only from 100 to 110 lbs. boiler pressure, and with the same piston-speed of from 500 to 600 feet per minute. The plan

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of stoking the fires all round about every twenty-four minutes he considered was a serious mistake, and he should have preferred to stoke them in two sets alternately at intervals of twelve minutes. Whenever any fire had just been replenished, there was a vigorous and quick distillation of volatile gases; and especially with flues the heat left above the fire was not sufficient to ignite a large portion of those volatile gases; and the neighbouring fire being in as bad a condition in consequence of all being stoked together, smoke was produced, which passed through the tubes and escaped unconsumed up the chimney, detracting from the effective value of the coal, and producing a dense black cloud from the top of the chimney. The consequence was seen to be that, even with 147 lbs. boiler pressure and 363° temperature, the maximum power obtained appeared from page 249 to have been less than 13 indicated horse-power per square foot of fire-grate; and the boiler was therefore not doing work equivalent to that of the ordinary boilers which had been made by hundreds in Lancashire and Yorkshire for compound engines working with a pressure of only 110 lbs. The coal used in the trial might be called a moderate steam coal. The analysis of it was not as complete as he should like to have, because the nitrogen, sulphur, and oxygen were not given separately, but were all three put down together at 10 per cent. There must have been a considerable amount of sulphur, because of the large quantity of clinker, which most probably was sulphate of iron.

As regarded the working of the engine, the indicator diagram from the high-pressure cylinder in Fig. 5, Plate 47, did not show anything like a clean cut-off. He should also like to see its exhaust side following the steam side of the next cylinder more accurately. In the quadruple engine already referred to, of double tandem action, and without intermediate receivers except between the second and third cylinders, a considerable uniformity was obtained between the exhaust side of the high-pressure cylinder and the steam side of the following cylinder by cutting away liberally the exhaust side of the valve. But that uniformity it must be manifest implied a considerable over-lap of temperature in the two cylinders, because the exhaust terminal pressure and temperature in the first cylinder

were lower than the initial pressure and temperature in the second, which was a desirable condition. When originally contemplating the construction of triple and quadruple engines, he had naturally regarded the steam engine more as a heat engine than as merely an apparatus for the expansive working of steam; and had therefore considered what would be the best or probable range of temperature between the initial and the terminal pressure of each cylinder. From the evidence afforded by a large number of Lancashire mill-engines, both compound and single-cylinder, he had found that the greatest range of temperature in any one cylinder, which corresponded with the highest degree of expansion, usually gave worse results than a lower range of temperature and expansion. It was therefore manifest that in order to get the highest possible duty out of high-pressure hot steam it must be worked while at high pressure in a hot cylinder only, and afterwards at lower pressure in a larger cylinder. He did not agree in the desirability of jacketing the low-pressure cylinder with steam not more than 10 lbs. above the initial working pressure in that cylinder, as mentioned by Mr. List (page 267); but neither was he an advocate for jacketing the first or high-pressure cylinder. Where there was so high a temperature as 363° Fahr. for the initial steam in the high-pressure cylinder, there was naturally some tendency at high speeds to the piston grooving, galling, or seizing the cylinder. If the high-pressure cylinder was jacketed at all, it should not be jacketed with steam at lower pressure and therefore lower temperature than the initial steam inside the cylinder, as seemed from page 242 to have been the case with the high-pressure cylinder in the trial, where the boiler pressure was 145 lbs., while the pressure in the first jacket was only 131 lbs. If it was practically desirable to work high-pressure hot steam at 360° temperature in a jacketed cylinder, it was far more practical and far more desirable he considered to jacket the intermediate and low-pressure cylinders with steam at the same temperature of 360°, and thereby call into operation the law discovered by Dalton in Manchester in 1801, and by Gay Lussac in France at the same time, that under constant pressure steam and all gases doubled their volume at 32° Fahr. by increasing their temperature 480° above 32°. Now

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going on further to the low-pressure cylinder, it seemed to him strange to jacket it with steam at only 56 lbs. pressure having a temperature of 301°, when the boiler steam of 360° might be used without any doubt of success, increasing the temperature in the jacket, and giving rise to 20 or 30 per cent. increase of volume in the steam used in the low-pressure cylinder alone. The practice he recommended was thus in the inverse order of the course exemplified in page 212 of the report; and unless that practice was carried out, he was of opinion that the success which ought to be attained with triple-expansion engines would not be realised.

With regard to the power developed by the three several cylinders (page 243), he should certainly aim in triple or quadruple engines at getting as much duty out of the first cylinder as out of the second, and approximately as out of the third or fourth. This had not been accomplished in the trial reported. Taking the set of indicator diagrams shown in Plate 47, the indicated horse-power recorded on them for the successive cylinders was seen to be 666 in the first, 512 in the second, and 831 in the third. In his own practice he always endeavoured to get as much work as possible out of the steam before it was expanded down to atmospheric pressure; because when it reached that pressure in the low-pressure cylinder, as it usually did at about half stroke as seen in Fig. 7, Plate 47, it had already done about three-quarters of all the work it could do in that cylinder, as also seen from the same diagram; and there remained therefore only the one quarter more to be gained from the latter half of the stroke. In the present case the first two cylinders together yielded a total of only 1,178 HP., while the third alone yielded 831; whereas with 2,009 total indicated HP. in the three cylinders he was satisfied an engine could not be considered economical unless at least two-thirds of its power, or fully 1,400 HP., were developed in the first two cylinders. Engines so proportioned he was satisfied would give an indicated horse-power for at least as little as $1\frac{1}{4}$ lbs. of coal per hour. The report appeared to him to present an accurate record of an engine that was not doing such good work as it might do; and the efforts of the Committee he thought should be directed to illustrating what could be done by the best engines, instead of to

obtaining results from inferior engines. The present record he hoped would lead to better practice in the future: particularly as regarded the amount of reduction of temperature which should be permitted in any one cylinder, and the time which should be allowed for it to take place in. At a former meeting (Proceedings 1881, page 502) he had dwelt upon the practical advantage of distributing the action of high-pressure steam over three or four crank-pins, whereby a marine engine could be run at a high piston-speed without heating the journals, and without any possible chance of injury to the screw-propeller shaft. It was true that some engineers were of opinion that one cylinder was practically as good as three or four, as regarded the expansive action; but certainly with regard to practical results there could be no question that by the use of three or four cylinders, each striking a blow of only a third or a quarter of the force on the crank-pin, the endurance of the crank shaft must necessarily be greatly enhanced, while at the same time its diameter might be diminished and its speed of revolution increased. A higher velocity he was convinced was a most important element in realising the highest duty from every cylinder, whether high-pressure or low-pressure steam was put into it, especially with multiple cylinders.

Professor James H. Cotterill considered the data furnished in the report were rendered particularly valuable by the large scale on which the experiments had been made and by their accuracy, and also by the fact that the engine on which they had been carried out was a triple-expansion engine. With regard to the criterion of perfection that should be adopted, it seemed to him that the question was mainly one of practical convenience, and that there must of necessity be something conventional and arbitrary in any standard of perfection. For instance, in the case of an ordinary condensing engine working between the limits of temperature of the boiler and the condenser, why was it that for the superior limit the temperature taken should be that of the boiler, and not that of the furnace? Evidently because the loss of temperature between the furnace and the boiler was regarded as inherent in the nature of every steam engine. Again in a non-condensing engine, why was the lower

(Professor James H. Cotterill.)

temperature taken at 212°, corresponding with the pressure of the atmosphere? Evidently because the excess of pressure of the atmosphere above that in a condenser was regarded as a loss inherent in the nature of a non-condensing engine. In all cases therefore it was necessary to consider at the outset, in reference to the standard of perfection to be adopted, what were the losses inherent in the nature of the engine. Therefore the question raised by Mr. Willans and Mr. Macfarlane Gray seemed to be, whether the loss by misapplication of heat to the feed water was to be regarded as one that was inherent in the nature of the engine, or whether it should be regarded as one that could be avoided. Instead of applying heat direct to the feed water, it was possible theoretically to raise its temperature by compressing condensed steam before it was wholly condensed, and so raising its temperature to that of the boiler.* This had even been attempted practically; and if it had not yet succeeded in practice, the reason was not because the principle in itself was not right, but simply because the practical difficulties at present in the way were such that the gain was not equal to the loss which would be involved on account of friction and so on. It appeared to him that the question in regard to any standard of perfection was whether the loss was or was not to be regarded as inherent in the nature of the engine. If it were regarded as a loss which could theoretically be avoided, then the formula which gave the higher standard was the right formula to adopt. If, on the other hand, all idea of reducing the loss were given up, then the lower standard of perfection was right, as taking that fact into account. As a matter of practice he should certainly say that this particular loss in an ordinary steam-engine might now be regarded as unavoidable, and that the better standard of perfection to take was therefore that which recognised the operation of an ordinary steam-engine. Still he thought it worth while to point out that it was really a conventional question, a matter of convenience, not a matter of principle.

As to the liquefaction in the cylinders (page 245), it was striking to see how nearly equal the liquefaction was in the three cylinders.

* The Steam Engine considered as a Heat Engine; by James H. Cotterill. 1878, pages 202-3.

The comparison was of course imperfect, because no measurements of jacket water were given, and therefore the precise amount of liquefaction in the cylinder itself could not be known with certainty. But liquefaction in the jacket seemed to imply liquefaction in the cylinder; the one was necessarily dependent more or less on the other. Therefore it could not be doubted that there must be considerable liquefaction in the cylinder itself; and it would seem that the three cylinders were nearly equal in this matter, and they would be still more nearly equal if the difference in the range of temperatures in the three were taken into account. It was striking to find that this was so, when it was considered that the surface in the low-pressure cylinder must be so very much greater than in the high-pressure cylinder. There was a difficulty in the way of supposing that no condensation of steam was produced by the cylinder surface. Of course the very fact that there was liquefaction in the jacket made it difficult to suppose that the metal of the cylinder itself was not operative in condensing the steam during the stroke, and that any water present in the cylinder was simply a consequence of that which remained after the exhaust, collected together in small quantities in the angles of the piston, or deposited in a dew on the cylinder walls. The suggestion made by Major English (Proceedings 1887, page 505), and, if he mistook not, by Mr. Willans * also, seemed to be worthy of consideration: whether the action of a square foot of condensing surface was not greater with steam at a higher density than at a lower density. Such was known to be the case in the heating and cooling of air by surfaces; the same might perhaps be true for steam, though the two cases were very different.

With regard to the method adopted for expanding or combining the three diagrams in Plate 48, it seemed to him that the expansion of the diagrams should be in proportion not to the actual volume of the cylinders but to their effective volume, taking account not merely of clearance but of compression; whereas in Plate 48 he understood that the actual volumes of the cylinders were taken for making the

* Proceedings of the Institution of Civil Engineers, vol. xciii, 1888, page 155.

(Professor James H. Cotterill.)

expansion, including the total clearance space. Then the process of subtraction adopted in setting back the dotted curves to the zero ordinate of volume was no doubt valid so far as concerned the process of admission and expansion before the steam was released; but it seemed to give no useful information after release, during the process of exhaustion and compression.

Major ENGLISH, R.E., enquired whether any special importance was attached to the combination of the three indicator diagrams in Plates 48 and 49, and whether one mode of combining was considered better than the other, or whether there was any advantage in combining the diagrams at all. If the diagrams were combined in either of the ways shown, it appeared to him that, in considering any question connected with initial condensation or re-evaporation, the changes which the steam might undergo in the receivers between the cylinders ought to be taken into account, in order to make any comparison either with a single saturation curve or with a separate curve for each cylinder. It would therefore be necessary to get indicator diagrams also from the two receivers. It seemed to him however that in considering the question of condensation there was very little occasion to combine the diagrams at all, and that each cylinder could well be treated as a separate engine, receiving steam either in the case of the high-pressure cylinder from the boiler, or in the case of the others from the receiver which acted as a boiler. For all questions of condensation the calculations would be much simplified by treating each cylinder in a separate manner. His only reason for alluding to this matter was that, where reference was made in the report (page 246) to such calculations based on the experiments, the combined diagrams only were mentioned. One other question that he would ask was whether the area of the initial condensing surfaces under the valves could be approximately ascertained; if so it would facilitate some calculations. Also could the volumes of the two receivers be stated?

Professor W. CAWTHORNE UNWIN, member of the Committee, having had a good deal to do with experimenting on steam engines, sometimes

not under the best conditions, would enter a protest against Mr. Adamson's view that the experiments ought to be conducted only with the best engines. In such experiments as these the object sought was to understand the action of the steam in the engine; and often more light would be thrown on this subject, and the construction of good engines would be better advanced, by experimenting with steam acting in bad conditions than when acting in good conditions. Furthermore these experiments had been made with a triple engine usually reckoned to be of a pretty good type, but about which hitherto no exact data had been ascertained as to the amount of steam used. It was a gain to science to know that an engine of this kind worked with 15 lbs. of feed water per indicated horse-power per hour; and as it worked with this amount of feed water, he was inclined to think it was after all not a bad engine. There were few engines, on which anything like accurate experiments had been made, that were working with a smaller amount of steam.

In reference to the combined and expanded indicator diagrams on which saturation curves were drawn, Plates 48 and 49, diagrams of this kind were meant to convey information to engineers; and in order that they might do so readily, they should become recognised conventions; and therefore there was some use in discussing what form of diagram was most convenient, in order that it might be generally adopted, and that it might therefore be seen at once what the diagram meant. Two modes of combining diagrams were shown, and the report rather implied that they both conveyed the same information; but he wished to point out that this was not the case, and that there was a distinct convenience in adopting one of those modes rather than the other. In the first mode of combining the diagrams, shown in Plate 48, it appeared to him that two different modes of dealing with the diagrams, having two quite different objects, had got mixed together. In the discussion on Mr. Willans's paper (Proceedings Inst. Civil Engineers, vol. xciii, 1888, page 220, and Fig. 5, Plate 4) Mr. Macfarlane Gray had given a diagram very similar to that in Plate 48. The horizontal intercepts of the diagram, such as DE, were carried back to the zero line at AB. Thus the clearance was eliminated, and diagrams like the

(Professor W. Cawthorne Unwin.)

dotted diagrams in Plate 48 were obtained of the same area as the actual diagrams. But then in Mr. Macfarlane Gray's diagram the line SS was not a saturation curve, but an adiabatic curve; and the reason was clear. Mr. Gray's object was to compare the area of the actual diagrams obtained in an engine with the area which would be obtained in what might be regarded as a practically perfect engine. The area to the adiabatic curve was the work which would be obtained in an engine with perfect valve-gear, without clearance or waste spaces, and in which there was no condensing action of the cylinder wall. The whole object of Mr. Gray's diagram was this comparison of areas. If the actual diagrams gave say 77 per cent. of the area to the adiabatic curve, that conveyed quite definite and distinct information as to the degree in which the more or less removable defects of the steam engine had been overcome.

In Professor Kennedy's diagrams, Plate 48, a saturation curve SS was drawn, in place of an adiabatic curve; and therefore there was no longer place for a comparison of areas. The only object of drawing a saturation curve was to examine the condition of the steam as to dryness; and if this were the object, then he thought that the diagram in Plate 49 gave a right result, and the diagram in Plate 48 an erroneous result. Professor Kennedy had said that the ratio of AB to AC in Plate 48 was the dryness fraction of the steam. The dryness fraction must be the dryness fraction at some definite point of the stroke. It was true that AC represented the volume of so much steam as entered the cylinder per stroke. But AB was not the actual volume of steam in the cylinder at any given point of the stroke; it was the difference between the quantity of steam in the cylinder at a point of the forward stroke, and that in the cylinder at a corresponding point of the backward stroke. AB $\div$ AC was therefore not a ratio which gave the condition of the steam at any period of its action in the engine.

If however the diagram was plotted out as shown in Plate 49, then one fact about the action of the engine was arrived at, which it was useful to study just now. Unfortunately in drawing the saturation curve in this diagram the jacket steam was included; and that appeared to him to make it useless to draw a saturation curve at

all. But if the jacket steam were excluded, then the diagram did really give the actual dryness fraction of the steam for every point of the expansion. Taking any horizontal abscissa, QA was the clearance steam, AC the steam admitted per stroke, QB the steam existing as steam in the cylinder and clearance; consequently BC was the steam which must be condensed and existing as water in the cylinder and clearance. The dryness fraction was QB ÷ QC. Of course that was not everything which was wanted to be known about the diagrams. But it did give quite accurately and distinctly one set of facts which it was useful to know. According to the run of the saturation curve in Plate 49, supposing it drawn with the jacket steam excluded, it could be seen at a glance whether condensation or re-evaporation was going on in the engine during expansion, and whether the action of the cylinder wall was important or not.

Mr. JOHN G. MAIR, Member of Council, and member of the Committee, was of opinion that the question of the standard by which to compare engines was one of considerable importance. In deducing from an indicator diagram the work done, the diagram should be measured down to a line of perfect vacuum, because often a bad air-pump or inefficient means of condensation would give an imperfect vacuum; and the loss from this source was greater in proportion with a high rate of expansion and consequently a small mean pressure, than with an engine carrying steam farther through the stroke and having therefore a greater mean pressure. No doubt from a commercial point of view the air-pump and condensing arrangements should be taken as part of the engine; but for scientific purposes the above loss should not be allowed to influence the comparison, as it otherwise so unfairly did.

It was a question whether the steam engine as it now existed could properly be compared with a perfect heat-engine according to Carnot's theory; and it was doubtful whether Carnot himself would so apply his theory, inasmuch as the conditions of working with air or with a permanent gas were absolutely different from those that pertained to a fluid like steam, working in a cylinder of which the walls were alternately condensers and evaporators, and in

(Mr. John G. Mair.)
each capacity produced a greater effect on steam than on a permanent gas: on this point he agreed with Mr. Willans and Mr. Gray. Although it was known that the application of a steam-jacket was directly counter to the requirements of a perfect engine as laid down by Carnot, nevertheless such a misapplication of heat did directly tend to economy. Incomplete expansion was another source of serious loss which could not be avoided; while at the same time the peculiar nature of steam, which, unlike a permanent gas, contained so much internal heat, required that the exhaust to the condenser should be closed before the termination of the stroke, and that the mixture of water and steam then existing in the cylinder should be raised to the boiler temperature by compression, and not by heat as was now done. Thus the steam engine, on account of the present methods of working the fluid in it, did not by a long way conform with a perfect heat-engine; and it therefore appeared that it was certainly not a practical way to compare the efficiency of steam engines by Carnot's theory. It was better by far to take the heat used by the engine, and to compare the power actually developed therefrom with the power equivalent to the heat used. In the "Meteor" trial 265·6 thermal units were used per indicated horse-power per minute (page 244); and comparing this with the equivalent of one horse-power per minute, or 42·75 thermal units, the absolute efficiency was 16·1 per cent. The engine of the "Meteor" had been spoken of by Mr. Adamson as not a good engine; but he considered it was a good one, inasmuch as the best result he knew of previously published was that obtained with the Boston sewage engine, a compound engine designed by Mr. E. D. Leavitt, which used 274 thermal units per horse-power per minute, showing in comparison with the 42·75 thermal units per horse-power an actual efficiency of 15·5 per cent. It was true that the indicator diagrams from the "Meteor" were not perfect; but it was well known that it was not always the best looking diagrams which gave the most economical results. From Plate 49 it was seen that the expanded diagrams covered only about two-thirds of the total area which would be occupied by perfect diagrams: so that there was evidently some room for improvement.

Mr. William Anderson, Vice-President, and member of the Committee, pointed out that the subject of the report was not the quality of the engine, which the owners had been good enough to lend for the purpose of this trial; nor were the Committee responsible for the alleged bad stoking. The engine had been doing its regular work, and the experimenters had been there only on sufferance, to make such observations as they could during the regular working of the engine. No one who was not a marine-engine builder would be likely he thought to succeed in making a better engine, or even one so good. A marine engine was not to be judged by the indicator diagrams alone, but by many other points of great importance; so that the construction of a marine engine required a great deal of experience as well as theoretical knowledge. All the documents and facts collected in this trial would be preserved in the Institution, so that any one who was much interested in the subject would be able to get all the data from the original papers.

In the analysis of the coal (page 237) he noticed what was somewhat unusual, namely that 10·68 per cent. of water was included, by which he supposed was meant the dampness of the coal. In regard to the calorific value of the coal, which was given as 12,790 thermal units (page 238), he should like to know whether this included the water, or whether it was calculated on the dry fuel. Again the statement on page 244 did not seem quite clear as to the difference between ash and clinker. It was stated that "the sample of coal analysed being free from clinker, the 4 per cent. of clinker may roughly be said to correspond to a loss of about 3 per cent. of the whole heat." The analysis (p. 237) spoke of ash only; but in this he supposed were included materials of which clinker was composed, except what came from the fire-bars, which however could not be much. Perhaps Professor Kennedy would explain the difficulty.

Another point on which he should like information was as to the means by which the feed water was heated in the apparatus devised by Mr. Clephane (page 241); whence came the heat imparted to the feed water?

Of these experiments, which were the best that could be made under the circumstances, it was impossible to speak too highly

(Mr. William Anderson.)

either as to their value or as to the way in which they had been carried out. Some of the desired data however had not been obtained; and he hoped therefore that the experiments would be repeated at no distant day, and that, profiting by the experience already acquired, the deficiencies would be made good. The unfortunate accident to the bottles of gases was greatly to be regretted, because there was only one analysis available (page 241); and he thought it was doubtful whether much could be built upon this, because it further appeared (page 244) that the quantity of air, 22 lbs. per pound of carbon, must be a great deal too high. The depth of the fuel on the fire-bars, he thought, would militate much against so large a consumption of air. Coal of the quality used would hardly require theoretically more than 11 lbs. of air, and 18 lbs. would be a very liberal allowance per pound of coal. Moreover in the theoretical aspect of the experiments it was assumed that the steam-jackets, the cylinder liners, and the piston-valves were tight, and in fact that the engine was mechanically perfect; but this was hardly likely to be the case, especially with piston-valves. He agreed with Mr. List (page 269) that it would have been better if the low-pressure cylinder had been fitted with a slide-valve, because there was a considerable difficulty in keeping large piston-valves tight.

Mr. John R. Fothergill considered there could be no question as to the great advantage of a standard system of engine testing, determined from actual data obtained from the working of marine engines under normal conditions; but in order that any such mode of comparison should be of practical value, the method of investigation should be most complete in every detail, so as to receive universal approval. If it was in the power of the Committee, it appeared to him that they should particularly endeavour to choose for investigation such engines as might in their general dimensions and details compare with the most accepted practice of the principal marine-engine builders; for the fact must be recognised that engine builders of late years had not been working in the dark: most of the principal firms had a scientific staff in connection with their works, by whom he

would suggest that a preliminary enquiry or trial should be carried out, before complete arrangements were made for a thorough investigation.

In the "Meteor" he noted the ratio of the cylinders did not conform with the practice of many builders: the high-pressure cylinder was exceptionally large in proportion to the low-pressure, and there was no doubt the stresses and strains must consequently be heavy. In the indicator diagrams shown in Plate 47, representing the average of those taken during the trial, and he presumed at the usual running speed, it would be noticed that the intermediate cylinder showed 23 per cent. less power than the high-pressure, whereas the low-pressure showed 24 per cent. more than the high-pressure; this certainly should not be the case in a well-arranged engine. Then again the range of temperature in the several cylinders appeared to be most unsatisfactory; in the high-pressure cylinder he made it out to be 78° Fahr., in the intermediate 59°, and in the low-pressure cylinder 98°. Therefore the intermediate cylinder showed a range of temperature 24 per cent. less than in the high-pressure, and the low-pressure cylinder showed a range 66 per cent. more than in the intermediate. The indicator diagrams illustrating the paper by the late Mr. Wyllie, read at the autumn meeting in 1886 (Proceedings 1886, page 473), showed that there was no difficulty in obtaining an equal distribution of power and range of temperature, with the initial stresses well balanced. When the "Meteor" engines were spoken of in the present report (page 245) as being very economical, he presumed that the meaning was as compared with the generality of marine engines. In respect of the steam used or water evaporated for the indicated horse-power developed, there was no doubt they were most economical; but the manner in which the engines were indicated was different from the usual practice, and therefore where was the comparison? In page 240 it was stated that the "indicators were used, one on each end of each cylinder; the connections in all cases were through only a few inches of large pipe having in no case more than one bend." In nearly all previous cases marine engines had been indicated through from 3 to 4 feet of copper pipe, much exposed, having several bends, some

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of them at right angles. Had the "Meteor" engines been indicated under such conditions, he was sure they would have shown 5 to 10 per cent. less horse-power developed, which would have materially affected the working out of the efficiency. Without raising any objection to the manner in which these engines had been indicated, he pointed out that the special means taken to indicate them had resulted in a special and unusual horse-power; and he was therefore of opinion that the horse-power so arrived at ought not to be used in comparing the "Meteor" engines with those indicated under ordinary conditions. Several engines that he knew of would prove equally economical if indicated in the same manner.

As to the measurement of the feed water, it was certainly unfortunate that the Committee had not been able to ascertain the water from the jackets and from the steam used for heating the feed, for this was really of vital importance in calculating the efficiency of the engines. In the majority of steamers the water required to make up the loss was supplied from the sea; but in the present case the exhaust from various engines using steam from the donkey boiler had been more than sufficient, and he should like to know what allowance had been made for the feed so obtained from the donkey boiler, as against the usual supplementary feed from the sea. For it appeared to him that the heat required to raise the temperature of sea-water to that of the feed should be fully allowed for, as against the temperature of the exhaust steam from various engines. From his own experience with triple engines he had found that a minimum of three to four inches of water measured at the gauge-glass was required to be supplied to each boiler per 24 hours. In any future trials therefore he would suggest that great consideration should be given to this subject. He fully realised the great difficulty of ascertaining the true efficiency of boilers and the actual work got out of the coal. The first consideration was the condition of the boilers in regard to scale, and then the duration of the trial and the time of continuous steaming. Of course the evaporative efficiency of furnaces and tubes free from scale materially affected the result. During a few hours' run the tubes were clean, and so were the fires, and therefore the coal was consumed to the best

advantage, as there was no necessity for constant raking and pricking of fires. The taking of the funnel temperature he had found of great value in his forced-draught experiments, and his experience in this matter had been that the temperature in the funnel varied much during the first few days of steaming; after the first 30 or 40 hours at sea he had generally found an increase in the funnel temperature of 100° to 150° and even more. It was unfortunate that only one sample of furnace gas had been saved; for the analysis of the other samples would have been of great value, and he fancied would have shown a mean result different from the analysis given. The one sample analysed he should imagine had been taken just before firing, and when the fires were in good condition, for the percentage of carbonic oxide was so small; additional analyses he thought would have shown it much larger, considering the small supply of air amounting to only 15·5 lbs. per lb. of coal, and considering that the boilers worked under natural draught.

The coal consumption of 19·25 lbs. per square foot of grate per hour (page 243) was exceedingly large for natural draught, more particularly considering the small supply of air; and a grate of 6 feet length could not be efficiently fired in a marine boiler. Taking the coal consumption as a basis of comparison, he failed to find these engines so economical as the report described them; the consumption appeared to be 2·01 lbs. per indicated horse-power per hour (page 247). The analysis of the coal gave a calorific value of 12,790 thermal units per lb., equal to $13\frac{1}{4}$ lbs. of water evaporated from 212° Fahr. per lb. of coal. Fairly good Newcastle coal gave about 14,000 thermal units, with an evaporation of $14\frac{1}{2}$ lbs., showing that the coal here used was about 8 per cent. inferior to ordinary Newcastle coal; and therefore, had the coal been Newcastle, the consumption would have been about 1·8 lb. per indicated horse-power per hour. To his own knowledge there were many triple engines running under ordinary conditions, in which the consumption of Newcastle coal did not exceed 1·6 lb. per indicated horse-power per hour, the engines being indicated in the ordinary manner.

Had the object of the present report been simply to show what a particular engine did, then of course the whole consideration would

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have been different; but as a basis of comparison he urged that it was of the utmost importance in such investigations that the greatest care should be taken to obtain engines which conformed with general practice, and that the trials should be made under the condition of ordinary working; otherwise it would be difficult to establish a reliable standard system. He desired to express his own thanks to the Committee, and felt sure that with the experience they had obtained any future report would be of the greatest value.

Mr. D. B. Morison thought it would now be admitted that there was considerable difficulty and expense attending marine-engine trials; for in the case of the "Meteor" a special staff of seventeen had been necessary, even under the exceptionally favourable condition of fine weather throughout. The value of the report lay not so much in the design of the engine as in the accuracy of the results obtained. All marine engineers would admit that the ordinary trials of coal consumption were unreliable and incorrect, and were simply so managed as to satisfy the specified requirements. In trials also of indicated horse-power a skilful operator with a little assistance from the engineer in charge could obtain results which were absurdly incorrect. This manipulation of trial-trip results must continue as long as engineers were bound by ship-owners to obtain practically impossible results; in fact the stipulations made were sometimes even dangerous, compelling a recourse to means which might impair the efficiency of the engines. It was only natural therefore that coal-consumption trials were less frequent, and that the maximum indicated horse-power obtained on a trial was looked upon with suspicion. The most interesting feature in the present trials was the measurement of the feed water, which certainly showed that the engine was very efficient; and this being so, he was naturally led to analyse the principal proportions. It would be generally admitted that the modern cargo steamer was a commercial success; and although the engine did not contain every possible refinement necessary to obtain the greatest possible economy, nothing whatever was omitted which experience had taught the ship-owner would give a good return on capital invested. It would

be interesting therefore to compare the efficient engines of the "Meteor" with cargo-boat practice. A cargo engine was generally unjacketed, and the ratio of high-pressure to low-pressure cylinder capacity was 1 to 7 or thereabouts: the "Meteor's" cylinders were jacketed, and the ratio was 1 to 5·67. The mean pressure in the "Meteor," reduced to the low-pressure cylinder, was 30 lbs. per square inch, and that in a cargo engine about 26 lbs. As regarded revolutions, the cargo engine was limited to the number that gave the greatest propeller efficiency, which was usually from 58 to 65 per minute. The most important question was therefore, what was the most economical ratio of expansion at which a triple-expansion engine should be worked; consequently a trial with a cargo-boat engine would be valuable and instructive. The many little details which Professor Kennedy had been compelled to assume as correct, and others which were not under the most favourable conditions for purposes of trial, showed that the various arrangements should be made during the actual construction of the engines; and this being so, he would himself endeavour to fit a cargo engine with all the details required for trial, and Professor Kennedy should be very welcome to supervise any trials he might make. It could not but be regretted that in the "Meteor" trial the jacket water had not been kept separate; or, if this was impossible, that the jackets had not been shut off entirely, as the result would then have been more definite and valuable. It would be interesting to know what was the feed-heating arrangement. A simple plan often met with for heating the feed water was to lead a pipe from the intermediate-cylinder steam-chest to the feed suction-pipe; and by that means, together with light feed-pump valves, the water might be heated and pumped without difficulty at a temperature of 170°. A convenient method of comparing the vacuum in the cylinder and condenser was to take a diagram from the condenser with the same indicator that was used for the low-pressure engine. If the "Meteor" vacuum was correctly shown by the indicator diagrams, the advantage was seen of feeding the boilers with an independent pump which could be regulated separately from the main engines; for it reduced the amount of air in the condenser to a minimum, thereby causing

(Mr. D. B. Morison.)

the pressure to correspond more nearly with the temperature. It was advantageous, he had found, to keep the initial pressure in the low-pressure cylinder well above atmospheric pressure: although, if this plan were carried to excess, it naturally followed that the initial loads on the three pistons were unequal, an example of which was the "Meteor" forced-draught trial with auxiliary steam, when the initial load on the high-pressure piston he calculated was 59,000 lbs. and that on the low-pressure piston 142,000 lbs. or nearly $2\frac{1}{2}$ times greater. The latter load was severe on the bearings and gear; in fact in the present case the low-pressure piston-rod seemed to be loaded to about 9,000 lbs. per square inch at the bottom of the screw-thread, which was rather too high a load.

With regard to the boilers, it was to be regretted that the coal was so inferior; but even taking this into consideration, the consumption of 2 lbs. per indicated horse-power per hour appeared high. The total heating surface of 6,648 square feet for 1,994 total indicated horse-power was equivalent to 3·33 square feet per indicated horse-power. Comparing again with a cargo-boat boiler, the usual allowance was about 3·6 square feet of total heating surface per average indicated horse-power at sea; the tubes were larger, and the consumption of coal per square foot of grate was about $14\frac{1}{2}$ lbs. per hour against $19\frac{1}{4}$ lbs. in the "Meteor." In the latter however the special requirements must be considered, as she was a fast passenger boat in which the greatest power from a given weight of boiler had evidently been aimed at, rather than the maximum efficiency, as evidenced by the use of fire-grates as much as 6 feet long, and by a rate of consumption so high as $19\frac{1}{4}$ lbs. of coal per square foot of grate per hour. Except where circumstances rendered it necessary, a grate 6 feet long was in his opinion most objectionable, as the efficiency of a furnace depended to a great extent on the manner the fire was kept up, and no ordinary fireman was able to do justice to a 6 feet grate. There was no doubt that the correct direction in which to go was to have a large diameter of furnace, and a length of $4\frac{1}{2}$ feet or a maximum of 5 feet for the grate; and one advantage gained by artificial draught and by

arrangements of mechanical fire-bars was that the grate could be shortened, owing to the more rapid combustion.

For taking indicator diagrams he had lately used an appliance which got rid to a certain extent of all the imperfections hitherto experienced during the actual taking of the diagrams. As illustrated in the vertical section, Fig. 25, Plate 55, the indicator piston was fitted with a separate bottom, with a central hole going up into the hollow interior of the piston. A shallow oil-groove was turned all round the circumference of the piston; and several small holes H were bored radially, leading from the interior to the groove. Before taking the diagrams the piston was charged with oil, which filled up the holes and groove. The steam pressure acting on the bottom of the piston passed up through the central hole, and pressed on the surface of the oil, so that the pressure in the groove round the piston was really equal to the pressure on the bottom of the piston. As a matter of fact diagrams could by this means be taken on a new engine without the slightest difficulty, and without any irregularities: as would be seen from the specimen diagram shown in Fig. 26, in which it would be noticed that there were but few imperfections or irregularities in the steam line; and this result was entirely due to the arrangement for constant lubrication.

Mr. John R. Fothergill mentioned that he had also used this plan of indicator piston with good effect on several occasions.

Mr. Frederick Edwards, as a member of the Committee, thought few persons had any idea of the difficulties that had been met with in connection with these trials. He had himself carried out many trials on land from six o'clock in the morning until six o'clock at night, and they were really child's play compared with marine trials. In the first run made with the "Crystal," previously to the "Meteor" trial, all the apparatus had been fitted on board the steamer for a trial from Middlesbrough to Dundee. Soon after starting, a patch on the back of the donkey-pump gave way and put an end to the work, so that they had their trip to Dundee for nothing. On the next occasion he went to Leith to join the

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"Meteor," and on arrival there found that the vessel had a hole knocked in her bottom by going on a rock, and he had to return from a fruitless journey. If all went well in the engine-room, which was not always the case, there was often a good chance of falling in with rough weather; while if the sea was smooth, there was a good chance of having a fog and of the engines being slowed in consequence. Then there was the possibility of the firemen not being sober, which was often a great difficulty. Besides the utmost care, a good deal of luck was wanted in order to get through the long trial without any stoppage.

In fairness to the builders, attention should be drawn to the sizes of the cylinders, which in the "Meteor" he thought had clearly been designed with a view to giving the utmost power that could be got out of them, and therefore he presumed they had never been intended to work with the greatest economy. The high-pressure cylinder being so large enabled the engines to give out great power; but at the same time this also made it difficult to cut off at a sufficiently early point for working the engines economically at a comparatively low power. The proportion of the tubes was one never adopted, as far as he knew, for natural draught, and it showed that the boilers had been designed to work with a forced draught; and therefore when working with a natural draught, as they had worked in the trial, it would not be expected to get such economical results from these boilers. The large power given out by the engines he considered was not only highly creditable to the builders, but also satisfactory from the owner's point of view.

The extra steam supplied to the main condenser from the auxiliary engines could make no difference in the measurements, because the water in the boiler was kept at the same level, and the surplus ran into the bilges and was not measured. Great importance was attached by himself to these trials; for he considered it quite as important to have a means of measuring the feed water as it was to measure the oil and the coal. If the feed water could only be measured accurately, it could be ascertained beyond all doubt which engines were the most economical, and what proportions to follow in the future. With this view he had already had one steamer fitted

permanently with feed-measuring tanks; and in all the new steamers building under his superintendence he intended to have them provided, if there was room to fit them conveniently in the engine-room. One at present building would have them, and he hoped that the Research Committee would test it. He had been devoting special attention to the matter, with a view if possible to make it a commercial success; that is, to see at how small a cost the tanks could be fitted and how little space they could be got into, so that the owners should not object to the first cost, and the engineers in charge should not be inconvenienced by the space being so occupied. He had found that no extra staff was required for working the tanks in the ordinary way; and that during the third engineer's watch, the chief and second could easily use the tanks for a short time in order to find out what was the consumption of water, and which was the most economical way of working the engines. Any increase or decrease in the consumption of the water would show itself immediately; it would not be necessary he considered to use the tanks for more than an hour at a time on each grade, in order to arrive at what were the best grades of expansion for the engines to run at. A small saving in water thus arrived at would soon pay for the cost of the tanks several times over.

The indicator diagrams shown in Plate 47 had been referred to by Mr. Adamson, who had disapproved of the cut-off as there exemplified. But without having communicated with the builders on the subject, it seemed to himself to be the common-sense view that the engines had been designed to work, not as shown in Plate 47, but as shown in Plate 52, working full power with forced draught; and the cut-off was there seen to be very fair indeed. Mr. Adamson he hoped, besides criticising what the Committee had done, would help them to get steamers to test. They had had difficulties in getting any engines to test, apart from the practical difficulties of carrying out such tests; there had as yet been few owners who had come forward with an offer of a ship that would suit exactly; and if Mr. Adamson would kindly aid in getting the steamers that were required, the Committee would be delighted to test them. There were perhaps some drawbacks in the engines already tested, when

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working under certain conditions; but it must be borne in mind that, in order to save the tide, these engines had been designed to give out the utmost power when going northwards, and that during the return journey southwards not so much power was required; consequently they had to work under two sets of conditions.

Previous to the commencement of these trials, in order to ascertain how accurately coal could be weighed at sea with a spring-balance, he had weighed twelve different quantities, put them in casks, brought them ashore, and afterwards weighed them on land. The percentage of error was only 0·417, or less than half of one per cent. He also found that a single spring-balance would weigh as much as 88 tons in 24 hours. The weather was not particularly rough; but as the ship was small and steaming 11 knots, the vibration of the spring-balance pointer was so great that it was impossible to take a reading of the largest and the smallest amounts. It was only by watching it carefully at certain times that an accurate reading could be obtained; and then the percentage of error was only 0·417, as already stated, these measurements being made with a pointer that was $\frac{3}{4}$ lb. broad.

The PRESIDENT asked whether the error might be on either side.

Mr. EDWARDS replied that it was all in one direction, the spring-balance indicating that percentage in excess of the coal actually weighed.

After the trial of the "Fusiyama," when he calibrated the water tanks he also tested what the percentage of error was likely to be. He found that the tanks held 260 lbs. each, and that when they were full the addition of $\frac{1}{2}$ lb. of water raised the level $2\frac{1}{2}$ inches. When using the tanks there was no difficulty in bringing the level at each time of filling to within about $\frac{1}{4}$ inch of the measurement mark; and if by accident in filling it happened to go up to $2\frac{1}{2}$ inches above the mark, the percentage of error would then be only 0·19, or less than one-fifth of one per cent.

Reference had been made to the condition of the boilers in the "Meteor" trial. He had himself gone into the furnaces and into the

combustion chambers; and as far as he could see, the furnaces, the combustion chambers, and the tubes were all in good order. The tubes were swept clean before starting on the trial. He wanted to go inside the boilers, to see what state they were in with regard to scale; but he had not the opportunity.

Two-cylinder compound engines were now being fitted in several cases with a third cylinder, and were working at 80 lbs. pressure with the original boilers, and carrying the full pressure nearly to the end of the stroke in the first cylinder, and were reported to be giving very good results. The Research Committee he hoped would have an opportunity afforded them of ascertaining what actual results were being obtained by triple-expansion engines working at such a low pressure.

He quite agreed with what Mr. List had said about steam-jackets. There was great difficulty in getting marine-engine builders to supply jacketed engines; they preferred to make them without the jackets. If it could be settled definitely what the saving in consumption was with or without the jackets, he thought it would be a great advantage.

Mr. Charles J. Wilson explained that in the coal analysis given in page 237 the concluding item of 10·67 per cent. had merely been taken by difference. The problem submitted to him had been only to determine the calorific value of the coal, nothing further. For this purpose the carbon, the hydrogen, and the water present had all been determined with considerable care, and from these three percentages the calorific value had been calculated. The nitrogen, the sulphur, and the oxygen had not been determined directly, but had been taken by difference; because, although they had a slight influence on the calorific value of the coal, he should not have known how to calculate that influence; it was for this reason that the sulphur had not been determined. Otherwise it was customary in coal analyses to determine the sulphur directly and the nitrogen directly, leaving only the oxygen to be taken by difference. In the present case, where the object had been to ascertain the calorific value of the fuel, only those determinations had been made which

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were directly concerned in that calculation. In comparing this coal with other coal, it was worth while to remember that the calculation of the calorific value was a matter on which chemists were scarcely agreed. The general custom was to deduct from the total hydrogen the amount necessary to combine with the oxygen present in the form of water, and to calculate the heat of combustion of the residual hydrogen only. This method gave results always too low, when compared with those obtained by combustion of the coal in a calorimeter. Results more nearly in accordance with calorimetric experiments were obtained by making no deduction for oxygen present, but calculating the heat of combustion of the whole quantity of hydrogen. The state of combination of the oxygen in coal was unknown; but the one form in which it appeared not to be, namely water, was the one in which it was generally assumed to exist.

With regard to the furnace gas, of which only one sample had been submitted to him for examination, it had been remarked that it was a pity there had not been a greater number of samples, in order to arrive at the average composition. It seemed to him to be always desirable to take a series of detached samples at short intervals, and to make analyses of those samples, and so get the average results. This he preferred to drawing off one continuous sample; because by taking several separate samples and making the analyses, not only was the average composition ascertained, but also what was the extent of the variation. In drawing samples of furnace gas from a flue for the purpose of analysis, it seemed to him essential that the gas should not be allowed to come in contact with any liquid other than mercury. It was true that a completely saturated solution of perfectly pure salt in water had only a very slight solvent action on the carbonic acid; but ordinary salt gave a perceptibly alkaline solution, sometimes more and sometimes less alkaline, according to the amount of impurity present. The ordinary brine that was used, which had an alkaline re-action, exercised a perceptible solvent action on carbonic acid, and consequently modified the composition of the furnace gas before it was subjected to analysis. When no smoke was produced, and the flue gases consisted only of carbonic acid, carbonic oxide, oxygen, and nitrogen, the analysis was simple

and satisfactory. But where there was smoke, a considerable loss of heat might occur, owing to the volatilisation of hydro-carbons. This loss he was at present unable to measure, the difficulties being very great in the way of the collection and examination of volatile matters from coal.

Mr. Druitt Halpin considered the Institution was greatly to be congratulated on the experiments of the Committee, which would certainly become standards of reference; and he was glad to understand that the trial now reported upon was not the last to be made, but that the Committee contemplated continuing their labours, and hoped to make an experiment with the "Colchester," which was one of the latest boats of the Great Eastern Railway, and was an exceedingly fine example of a compound with only two cylinders. Having crossed over in that boat a short time ago, he had admired her very much; and he thought no one would be found to co-operate more heartily in the trial than her chief engineer, Mr. Cartledge, who he was sure would render every assistance in his power. The systematic experiments now made he considered were of great value in upsetting the fancy figures which had hitherto been announced as to what boats were doing. In one instance some experiments on a large boat had been recorded with 1·23 lb. of coal per indicated horse-power per hour; but the statement had been accompanied by indicator diagrams, from which, although they were on a very small scale, it was at least possible to measure approximately the water; and without allowing anything for cylinder or jacket condensation, no less than between 13 and 14 lbs. of water per lb. of fuel would have had to be evaporated by the coal said to be used. Triple engines had been spoken of by Mr. Fothergill (page 285) as running under ordinary conditions on a consumption not exceeding 1·6 lb. of Newcastle coal per indicated horse-power per hour; and in a careful experiment he had himself succeeded in getting as good a result; but he knew what a lot of trouble it took to do so, and such a result was not a thing to be lightly spoken of with any engine.

As to the means adopted by the Committee for carrying out the tests, in the mode of measurement of the water, which was a most

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vital point, he did not agree with them. Their object had been, as previously stated, in the first place to determine whether it was practicable to make the requisite observations without stopping the boat; and secondly to get scientific data. But he thought there had also been one other object, which perhaps they had had in view without recognising it sufficiently: and that was, to popularize the possibility of such experiments; and he thought it would hardly be possible to continue extensively the plan that had now been carried out, which involved lumbering up the boat with specially fitted tanks for making the experiments. Mr. Edwards too had stated that he was fitting a boat with special tanks, so that the water might be measured at any time. This did not seem to himself however to be at all necessary, because accurate and reliable results were now being got with good meters. Very recently he had had a meter put into constant use for measuring a large supply of water; and meters could be got to register accurately, and could also be worked with a by-pass, so that even if they broke down temporarily no great harm would be done. On his proposal the engineer of a large ship indicating several thousand horse-power had put a meter in to measure the feed, and it was now working; but he had not yet learnt the results of what it was doing. One thing might have been done, which, although it would have caused a little trouble, would have given a good deal of additional information: the boiler had been fed with a Worthington pump, of which many of the Committee had had experience; and if, in connection with the accurate measurement of the water by the tanks, some data had been collected as to the efficiency of the pump, by putting a counter on it to register the number of strokes, the information so obtained would have been of great value. If the Committee had a similar case to deal with again, he hoped they would see their way to using a counter in connection with the Worthington pump.

The means taken for indicating the engines in these trials were certainly above all suspicion. It had been stated by Mr. Fothergill (page 284) that if the engines had been indicated in the ordinary way, with long pipes to the indicators, they would have shown 5 to 10 per cent. less power; and having himself had a definite case of that

kind, he was willing enough to believe that a much lower power would have been shown by the diagrams than had been actually developed, and consequently a much higher coal consumption per indicated horse-power. In one of his engines which had been fitted in the ordinary way with a long pipe coming round from each end of the cylinder to one indicator, it seemed as though the engine was not giving anything like the power it was intended to develop; but when the long bent pipes were taken away, and the indicator was put on a direct pipe of only a couple of inches length, the power increased 38 per cent. (Proceedings 1886, page 364). The power was properly developed by the engine, but had not been properly measured previously.

Reference had also been made to the pressures in the jackets. As one who did not believe in a wet blanket, he hoped it would not be supposed that there was any real difficulty in making jackets which would safely take the full boiler-pressure; certainly the full boiler-pressure ought to be got in the jackets. It was not a question however of pressure, but of temperature; the full temperature ought to be got in the jackets, in order to get the full efficiency out of them; the difficulties to be overcome he did not consider to be insuperable, or the object aimed at to be not worth taking the needful pains to accomplish. As a rule there was plenty of room for natural circulation in the jackets in a steamer having engines of the steam-hammer type as ordinarily used in the merchant service; and the engine cylinders were high enough above the boiler to allow of natural circulation of steam from the boiler to the jackets, and of water back from them to the boiler. If the pipes were large enough, say 2-inch pipes or larger, so that the available head was not lost in friction, there would be a continuous circulation in the natural way, without traps to drain the jackets; and the maximum efficiency would be obtained.

In a discussion three years ago on compound locomotives (Proceedings 1886, page 368) he had described some ribbed jackets, which he had used, as he thought, successfully. The design had been criticised by Professor Ryan, who held that the ribs were doing more harm than good, and that the jackets so made were not transmitting

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anything like the amount of heat that could be transmitted through plain jackets. At that time he had not the means of replying, not having then obtained the actual data; but he had them now. Thanks to Professor Unwin, who had given him facilities for weighing both steam and water, he had been able to carry out an exact experiment with two standard lengths of cast-iron heating pipes, one of them plain and the other ribbed, each 4 feet long and about 4 inches diameter and half an inch thick; jackets were put round the pipes, and steam was introduced into the jackets, and water inside the pipes. The result was found to be that in the ribbed pipe the rate of transmission of heat from the steam in the jacket to the water in the pipe was 3·28 times as great as in the plain pipe, thus justifying the view he had taken of the superiority of ribbed jackets.

With respect to Mr. Adamson's remark that the Committee ought not to test bad engines, how were they to know whether an engine was good or bad till they did test it? They could not tell merely by inspection; and often more was learnt by testing bad engines than by testing good ones. By these tests the Committee were able to put the saddle on the right horse. Engines using only 15 lbs. of water per indicated horse-power per hour he considered were very good indeed, taking into consideration all the circumstances, as well as the fact rightly pointed out by Mr. Anderson (page 282) that it was not known what condition the engines were in; it had not been stated whether the Committee had had facilities for testing the valves and pistons. They had taken the engine as it ran, and 15 lbs. of water was hard to beat; but the total efficiency of the whole machine from the ship-owner's point of view he did not consider satisfactory. The boiler was doing very badly indeed in evaporating from and at 212° no more than 8·21 lbs. of water per lb. of coal; and not only was it evaporating so little, but it was doing it at an abnormally slow rate. A boiler was like every other machine, in being required to work well not only in economy but also in speed. The only true way of looking at the efficiency of a boiler was in his opinion by determining the product of the economy and the rapidity of the evaporation, that is, by multiplying the weight of water evaporated per lb. of coal by the rate of evaporation per square foot of total

heating surface per hour. In the present instance these amounts were respectively 8·21 lbs. and 4·49 lbs., and the product of these figures was 36·86. In a locomotive boiler, according to the same mode of estimation, the result was found to be very different: from some data that he had put together at a former meeting (Proceedings 1884, page 111), the product instead of being 36·86 was about 100, so that the efficiency of a locomotive boiler was nearly three times as great.

A question had been raised (page 257) as to the correctness of the figure given in the report for the average rate of transmission of heat through the material of the boiler, namely 5,244 thermal units per square foot of heating surface per hour; and though he did not know whether there was any clerical error here or not, his argument was that the transmission of heat, like the transmission of water, was due to the head available for producing the transmission; and in the "Meteor" boiler he assumed there should be at least the same head as in the locomotive boiler. From a paper read by Mr. J. A. Longridge before the Institution of Civil Engineers (Proceedings 1878, vol. lii, page 105), it appeared that for locomotive boilers the rate of transmission per square foot of heating surface was 11 thermal units per hour per degree of difference in temperature. Assuming that in the present case the furnace temperature was 2,500°, and that of the gases 780°, the rate of transmission per square foot of heating surface was found to be only 3 thermal units per hour per degree of difference in temperature, being less than one-third of the rate in a locomotive boiler. Here therefore was another check which showed that the boiler was doing very badly, independently of the quality of the coal. In fact, as stated in the report (page 243), the heat utilised by the boiler was only 62 per cent. of the whole heat in the coal. Another trial had been published which Professor Kennedy had lately made,* in which he had got a result of 87 per cent.; and he would ask at what rate of evaporation or transmission per square foot per hour so very high a figure had been obtained.

* Mr. Thornycroft's Paper in the Transactions of the Institution of Naval Architects, 1889, page 276, on his Water-Tube Boilers for War-Ships. "Engineering," 26 April 1889, page 412.

Professor KENNEDY in reply said he was glad so many speakers had attached importance to the subject of the jacket-water measurement, because it would help the Committee to get this measurement made on another occasion. There were many difficulties, as everybody knew, in getting so many measurements, and they had had to be content with what they could get.

On the burning question of efficiency, it had been properly pointed out by Mr. Willans (page 262) that choice had to be made of some standard with which to compare the engine tested; and that the standard should be more or less like the actual engine. The standard with which the engine had been compared in the report was unquestionably very different from the actual engine itself; the standard with which Mr. Willans (page 263) and Mr. Macfarlane Gray (page 266) compared the engine was much nearer the engine itself. It appeared to him to be a question of expediency as to which standard should be used. He quite agreed with what Professor Cotterill had said upon that point (pages 273–4); and he thought there was so much in it that in the next report he should have pleasure in stating the efficiency according to both standards. The choice of a standard however, he was strongly of opinion, was essentially a matter of expediency and not of principle, and its importance appeared to him to have been much exaggerated. He wished to point out that, while it might be convenient to adopt a certain engine as an ideal steam-engine and to compare with it actual steam-engines, it was much more than convenient—it was vitally important—to insist that the highest conceivable efficiency for any heat engine, whether air or steam or gas, could be expressed always by the same ratio. In any heat engine, with whatever medium it might be worked, the highest possible efficiency that could be got out of it was represented by what was called the Carnot efficiency $\frac{T_1 - T_2}{T_1}$. If this were clearly understood, no more would be heard of latent-heat delusions; whereas the notion that steam engines were essentially different from air engines was certain to be perverted presently, by those who did not rightly understand the subject, to the support of the most misleading heresies. By whom it had first been pointed out that a steam engine might be conceived to work as a perfect heat-engine,

he did not know; but, as was well known,* it was possible to take as an ideal steam-engine one which received all its heat at one temperature and rejected all its heat at another, the cycle being completed by an adiabatic expansion and an adiabatic compression between those two temperatures: the compression being the process in which the temperature of the water was raised. From his own point of view both as an engineer and as a teacher, it appeared to him to be a matter of vital importance to be able to show that, if a steam engine were so worked, there could be got out of it the highest efficiency that could anyhow be got out of the steam, and that the efficiency would then be represented simply by the Carnot ratio, and the steam engine would be working as a perfect heat-engine. Of course he would be told that this was impossible, because the engine was worked by steam; and he admitted that no one had yet shown how to get over the practical difficulties of making an engine work in this way. But then for precisely similar reasons an air engine could not be worked perfectly. The difficulty of working a steam engine in that way was that a pump would have to be employed which would compress steam adiabatically and finally turn it all into water at the boiler temperature. This was physically out of the question, the difficulties being too great; but the physical difficulties of carrying out the correct changes in an air engine were just as great. Even supposing that the regenerator were perfect, yet the other difficulties were such that the working could not be carried out in practice without complications as impossible mechanically as was the impossibility of accomplishing the compression of steam into water. After all, it was only a question of the degree of similarity between the actual and the ideal. In Mr. Gray's ideal engine (page 266) it was assumed that the low-pressure cylinder was big enough to work the steam down to the back pressure; from the practical point of view that was a great difference from any actual engine, in which such immense cylinders could not be used. It was also assumed that it was possible somehow to save all the spaces between the three consecutive indicator diagrams; but there

* See for instance "The Steam Engine considered as a Heat Engine;" by James H. Cotterill. 1878, pages 117–118.

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was no conceivable arrangement of receiver that could save these losses, which were inherent in the compound engine. It was further assumed that the expansion was adiabatic; while in the actual engine the utmost pains were taken to prevent its being so. Neither standard really represented the actual engine, even in its ideal form; and having been so strongly assailed on this point, he wished again to insist that the difference between the standards was one of degree only, not of kind. Oddly enough, Mr. Willans (page 263) and Mr. Gray (page 266) by no means agreed as to what the efficiency of the "Meteor" engines actually was. This emphasised his own view that the absolute value of the ratio called efficiency had no great importance. The real value of calculated efficiencies was essentially comparative, not absolute. Different engines should be compared by some standard which should not vary with the different kinds of engines; and he did not quite understand how, according to Mr. Gray (page 266), the standard of comparison adopted in the report was a fair one for different engines of low pressure, but became wrong for those of high pressure. It would be noticed that in page 245 the comparison was not with a perfect engine working between the same limits of temperature and using the same weight of steam, but "receiving the same quantity of heat," which made a great difference in the result. In the accompanying Table 2 he had worked out the possible efficiencies of five different kinds of engines, both according to the method followed in the report, and also according to Mr. Gray's method; and a comparison of columns 6 and 8 showed that the possible efficiencies were not so totally different as according to Mr. Gray they ought to be. The Table included a quadruple-expansion engine working at 200 lbs. pressure above atmosphere and condensing; a triple-expansion engine working at 150 lbs. and condensing; an ordinary factory engine working at 60 lbs. pressure and condensing; a Watt engine working at 10 lbs. pressure and condensing; and a locomotive working at 150 lbs. non-condensing. This, he submitted, was a large range. Classifying the five engines in the order of the quantity of heat which they severally received per pound weight of steam supplied to each, as given in column 4,

TABLE 2.

Possible Efficiencies of five kinds of Engines, calculated according to two methods:—

Col. 6, method described in Report (page 245); Col. 8, method described by Mr. Macfarlane Gray (page 266).

1	2	3	4	5	6	7	8	9	10
					Heat which might possibly be turned into Work.				
Kind of Engine.	Boiler Pressure per sq. inch above atm.	Condenser Temperature.	Heat received per lb. weight of Steam.	Carnot Efficiency.	Method in Report.	Ratio to Factory engine.	Mr. Gray's method.	Ratio to Factory engine	Ratio of col. 7 to col. 9.
	Lbs.	Fahr.	Units.	Per cent.	Units.		Units.		
Quadruple expansion	200	120°	1128	33·9	383	1·285	315	1·260	1·020
Triple expansion .	150	120°	1121	32·1	360	1·208	327	1·193	1·013
Factory engine . .	60	120°	1106	27·0	298	1·000	271	1·000	1·000
Watt engine . .	10	120°	1087	20·1	219	0·735	205	0·718	0·982
Locomotive . . .	150	Exhaust 212°	1009	18·5	187	0·628	175	0·638	0·985

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it was seen that the factory engine happened to come in the middle place; and its possible efficiency according to the two methods of calculation was therefore taken for convenience as unity in the two ratio columns 7 and 9. Thus in the quadruple engine the possible efficiency calculated according to the method followed in the report was 1·285 times that possible in the factory engine, and according to Mr. Gray's method 1·260 times; and so on for the three other engines. The final column 10 gave the ratio of column 7 to column 9, showing that the maximum difference between the two methods of calculation did not exceed 2 per cent., which was not worth fighting about.

With regard to Mr. Adamson's remarks, some of them he thought were to be deprecated, inasmuch as the Committee were not responsible for the engines; and he was sorry that the question of their actual merits had been introduced, because he thought the criticism on them was not entirely just. In any case the design of the engines was not on its trial; the details of the machinery had not been described in the report, and it had not been intended that the engine builders should be put on their defence. Nevertheless he might say that if he were again designing a set of marine engines he should be proud if he could design a pair, or a triplet, that would do the work these engines were doing. For certain tidal reasons the engines were designed to run northwards from London to Leith five hours quicker than they came south. Their proper indicated horse-power going north was 3,000; coming south it was only 2,000. It had thus been necessary to design a set of engines which should work alternately under a forced draught at 3,000 I.H.P., and under a natural draught at 2,000 I.H.P. That was a difficult object to accomplish, and he thought the designer deserved the greatest credit for the way in which he had carried it out. There was also the question about the management of the fires during the trial. The fires could not be managed down in the stoke-hole in the same way that they could in carrying on trials with a stationary or a locomotive boiler. The firing in the "Meteor" had been fair ordinary firing, and it had been as good as the Committee could get; the fact that it had not been as good as it might be came out plainly enough from the results.

In reply to Mr. Fothergill's remarks he might explain that, however ready the ship-owners were said to be to allow their engines to be tested, it had been difficult to get even a single ship which the Committee might test in their own way. It was really not a case in which there was a possibility either of choosing from half-a-dozen engines, or of carrying out a preliminary trial, because the preliminary trial would itself have involved so much time and expense as to be out of the question.

With regard to the proper position of the indicators, he would only say that he was delighted to hear what had been said. If marine engineers were alive to the fact that they could get 5 or 10 per cent. more indicated horse-power out of the engines by putting indicators on properly than when they were not put on properly, he was quite satisfied. But surely it was not for the Committee to put the indicators on improperly in order to compare with other engines. The report had given the real indicated horse-power, as well as it could be measured; and it being admitted that this method of measuring the power was the right one, he thought that other engineers must come round to it, and not *vice versâ*.

As to Mr. Willans's criticism (page 262) about the heat supplied to raise the feed from 120° to 160°, it ought to be explained that this operation was really carried on by help of steam taken from the engine, so that this heat was in fact a part of the 528,700 thermal units, although not actually utilised in the boiler directly. Under these conditions he thought he was justified in stating the matter as he had done. The lower limit of temperature had been taken at 120°, after much discussion in committee, instead of 140°, the temperature corresponding with the back pressure. A good deal could be said in favour of either figure.

In reply to Major English (page 276), he had had the receiver volumes computed from the drawings, and found the receiver between the high-pressure and intermediate cylinders to be about 22·3 cubic feet, and that between the intermediate and low-pressure cylinders about 50·2 cubic feet. As to the meaning of the expanded indicator diagrams (page 276), he thought Professor Unwin had perhaps overlooked the description of Plate 48 in the report, in which it

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was distinctly stated (page 216) that AB was, as he had said in page 278, the difference between a volume during expansion and a volume during compression, at the same pressure.

The calorific value of the coal (page 281) was calculated simply from its carbon and hydrogen, and included the heat which would have to be expended in evaporating the 10·68 per cent. of water, which, as given on page 244 of the report, amounted to about 1·2 per cent. of the 12,790 thermal units. In the passage in the report (page 244) about the 4 per cent. of clinker, referred to by Mr. Anderson (page 281), the meaning was that much of the material which eventually formed the clinker was originally in stony and bad lumps in the coal, which was altogether of poor quality. Such lumps were rejected in making the sample for analysis, although they were of course put on the fire as part of the weighed coal. The coal gave only 3·46 per cent. of ash on analysis, but the ash and clinker together amounted on the trial to 6·5 per cent. It was on this ground that he thought the remark about the clinker in page 244 of the report was justified; but he quite admitted that the point was a doubtful one.

If Mr. Halpin were successful with his meter measurements (page 296), he hoped he would make the results known. At present the Committee had not been able to make up their minds that any meter could be trusted with these very large quantities of water and under the conditions of a marine engine. If such an instrument could be found, it would be an immense help in experimental work of this kind.

The PRESIDENT was sure the Members would all join in tendering a hearty vote of thanks to Professor Kennedy, as well as to the Committee of which he was Chairman, for the arduous task which they had so faithfully discharged for the benefit not only of the Institution but of engineers all over the world. With the name of Professor Kennedy that of Mr. Edwards should also be specially mentioned. He looked upon the present report as the starting point of a series of practical investigations, which could not fail to benefit the whole marine engineering world, and to redound to the credit of the Institution.

DESCRIPTION OF AN APPARATUS FOR DRYING IN VACUUM.

By Mr. EMIL PASSBURG, of Breslau.
Communicated through Mr. SAMUEL GEOGHEGAN, of Dublin.

Wet By-products.—The by-products consisting of wet grains from breweries, distilleries, &c., and of root-chips from sugar manufactories, form in many cases food-stuff of great value; but on account of the great quantity of water they contain, they are subject to rapid destruction by decomposition, and their nutritious qualities especially suffer most. The same cause also prohibits their carriage over any great distance. In the case of wet beer-grains for instance, carriage has to be paid for about 75 per cent. of water. Hitherto therefore it has been necessary to utilise these by-products on the spot where they are produced, or at least in close proximity thereto, as well as with the least possible delay. The natural consequence is a low price for such products, of which moreover the supply is often greater than the demand, and thus prevents their realising anything like their market value, particularly during the hot summer months, when plenty of other food-stuff is to be had. The old plan of preserving such perishable substances in pits or silos is only a very rough and poor remedy, and does not answer its purpose at all completely; for, notwithstanding all precautions, decomposition sets in, and a loss of as much as 50 per cent. in the nutritious qualities is generally sustained, while at the same time the moisture is by no means reduced, and consequently carriage still remains impracticable.

Importance of Drying.—It has long been endeavoured to overcome these disadvantages by removing the surplus moisture by drying the

by-products, so as to allow of storing and transporting them, and at the same time of realising their full market value. The result of such endeavours has been the construction of different kinds of drying machines, which has certainly been a step in the right direction, inasmuch as drying is undoubtedly the surest and safest way of preserving this class of perishable substances. The removal of the water overcomes at once the two great obstacles previously encountered. The rapid decomposition ceases; and carriage to a distance becomes practicable, because the reduction in weight is very considerable. The consequence is that these by-products so dried fetch their full market value.

To solve this problem however has not been so easy a task, because, besides the necessity of keeping the expenses of drying as low as possible, a low temperature also has to be employed during the drying process wherever it is wished that the dried substance should retain its chemical composition unchanged, which in any article of food is a most important point for enabling a profitable result to be obtained. In general two drawbacks have rendered themselves conspicuous in connection with the drying machines hitherto in use: either, in order to shorten the drying process as much as possible, and to make it sufficiently economical, too great a heat has been employed, with the unavoidable result of seriously deteriorating the nutritious qualities of the material; or else, when a longer time and a lower temperature have been employed for drying, the capacity of the machines has been so small that the working expenses have rendered the process unsuccessful commercially. In both cases the advantages of drying are outweighed by the disadvantages incurred; and it is on this account that the drying of such perishable by-products has not become more general, as it ought to have done in consideration of its importance.

Requirements in Drying.—The following are considered by the author to be the three essential requirements for a successful and economical process of drying:—firstly, cheap evaporation of the moisture; secondly, quick drying at a low temperature; thirdly, large capacity of the apparatus employed.

The removal of the moisture can be effected in either of two ways: either by slow evaporation; or by quick evaporation, that is, by boiling.

Slow Evaporation.—The principal idea carried into practice in machines acting by slow evaporation is to bring the wet substance repeatedly into contact with the inner surfaces of the apparatus, which are heated by steam, while at the same time a current of hot air is also passing through the substance for carrying off the moisture. This method requires much heat, because the hot-air current has to move at a considerable speed in order to shorten the drying process as much as possible; consequently a great quantity of heated air passes through and escapes unused. As a carrier of moisture hot air cannot in practice be charged beyond half its full saturation; and it is in fact considered a satisfactory result if even this proportion be attained. It is evident that a great amount of heat is here produced which is not used, and the expense of drying is accordingly high; whilst with scarcely half the cost for fuel a much quicker removal of the water is obtained by heating it to the boiling point.

Quick Evaporation by boiling.—This, as is well known, does not take place until the water to be evaporated is brought up to the boiling point and kept there, namely 212° Fahr. or 100° Cent. under atmospheric pressure. The vapour generated then escapes freely. Liquids are easily evaporated in this way, because by their motion consequent on boiling the heat is continuously conveyed from the heating surfaces right through the liquid. But it is different with solid substances, and many more difficulties have to be overcome, because convection of the heat ceases entirely in solids. The substance remains motionless, and consequently a much greater quantity of heat is required than with liquids for obtaining the same results. With less heat such results would only be possible if there were a great difference between the boiling point of the water contained in the substance to be dried and the temperature of the heating surfaces; but to carry this out in practice under atmospheric pressure would be impracticable, because steam of the required high

temperature for the heating surfaces would be of too high a pressure. Another drawback is that the temperature of boiling water under atmospheric pressure is so high that in most cases the nutritious qualities of the material to be dried would be seriously impaired thereby, and the value of the whole material as food-stuff would thus be lessened.

Evaporation in Vacuum.—All the foregoing disadvantages are avoided if the boiling point of water is lowered, that is, if the evaporation is carried out under vacuum. This plan is widely known and used for liquids, but not so for solid substances. For the latter it has first been successfully applied in practice by the author's vacuum-drying apparatus, which is designed to evaporate large quantities of water contained in solid substances, in as short a time and at as low a temperature and expense as possible. Former plans for drying solid substances have not possessed the capacity of the author's apparatus, firstly on account of their having been attempted on a much smaller scale, with much smaller heating surface; and secondly, on account of the water being evaporated by boiling under atmospheric pressure, whereas the evaporation cannot be done at less expense, in shorter time, and in smaller space, except when it is effected in a vacuum. Although it has often enough been tried to use a vacuum in practice for the drying of solid substances, as it has been so successfully employed for liquids, yet the attempt has always been given up again; and even for laboratory work the author is not aware of the plan having anywhere been applied.

Apparatus for Drying in Vacuum.—As shown in Figs. 1 to 4, Plates 56 to 58, the drying apparatus consists of a top horizontal cylinder A surmounted by a charging vessel C at one end, and a bottom horizontal cylinder B with a discharging vessel D beneath it at the same end. Both cylinders are encased in steam-jackets heated by exhaust steam. In the top cylinder works a revolving cast-iron screw S with hollow blades, Figs. 3 and 4, which is also heated by exhaust steam. The bottom cylinder contains a revolving drum of tubes T, consisting of one large central tube surrounded by

two dozen smaller ones, all fixed in tube-plates at both ends; this drum is heated by live steam direct from the boiler. The substance to be dried is fed into the charging vessel C through two manholes, and is carried along the top cylinder A by the screw creeper to the back end, where it drops through the valve U into the bottom cylinder B, in which it is lifted by blades attached to the drum T and travels forwards in the reverse direction; from the front end of the bottom cylinder it falls into the discharging vessel D through another valve V, having by this time become dried. The vapour arising during the process is carried off by an air-pump, through a dome and air-valve E on the top of the upper cylinder, and also through a throttle-valve F on the top of the lower cylinder; both of these valves are supplied with strainers.

As soon as the discharging vessel D is filled with dried material, the valve V connecting it with the bottom cylinder is shut, and the dried charge taken out without impairing the vacuum in the apparatus. When the charging vessel C requires replenishing, the intermediate valve U between the two cylinders is shut, and the charging vessel filled with a fresh supply of wet material; the vacuum still remains unimpaired in the bottom cylinder, and has to be restored only in the top cylinder after the charging vessel has been closed again.

The practical success of this apparatus is owing to the employment of the vacuum and to the arrangement of the heating surfaces, as well as to the construction in general, whereby the charging of the wet substance and discharging of the dried are effected without destroying the vacuum in the bottom cylinder, which constitutes the main drying chamber of the apparatus. In this vacuum the boiling point of the water contained in the wet material is brought down as low as 110° Fahr. or 43° Cent.; the difference between this temperature and that of the heating surfaces is amply sufficient for obtaining good results from the employment of exhaust steam for heating all the surfaces except the revolving drum of tubes. Under atmospheric pressure this difference of temperature would not exist; and to the same cause is also due the short time occupied in drying, notwithstanding the low temperature employed. The water contained

in the solid substance to be dried evaporates as soon as the latter is heated to about 110° Fahr.; and as long as there is any moisture to be removed the solid substance is not heated above this temperature. The dried product therefore remains perfectly unaltered in every respect, and is not in the least impaired in its chemical composition and nutritious properties by the drying process. But it is not only time that is gained; there is also a great saving in the cost of drying, because all the heat expended is here usefully employed, and the vapour leaving the apparatus is fully charged with moisture, which is a result widely different from that obtained by slow evaporation under atmospheric pressure. For solid substances containing moisture therefore this vacuum-drying apparatus is considered to be the most economical.

If all the water were evaporated from the substances to be dried, the latter would of course be heated up to the same temperature as the heating surface, and would thereby be injured. This was one of the drawbacks connected with former plans of drying; but it does not occur in the regular working of the vacuum apparatus, because such substances as beer grains or distillery grains, oats, barley, &c., are never completely dried, but are always taken out of the apparatus while still retaining from 7 to 12 per cent. of moisture. Even if they contained less, they would rapidly absorb again from the atmosphere such a quantity of moisture as their chemical composition allows.

Practical Applications.—This plan of drying is already in use for various solid substances, and the result has in every case been remarkably satisfactory. Wet grains from a brewery or distillery, containing from 75 to 78 per cent. of water, have by this drying process been converted in some localities from a worthless incumbrance into a food-stuff highly valued and sought after. The water is removed by evaporation only, no previous mechanical pressing being resorted to; hence absolutely the whole of the solid matter is retained, of which, in any process of pressing, a large proportion would have been carried off in a dissolved state in the water. The result is a dry food-stuff, rich in quality and good in appearance.

From malt the removal of the moisture which it contains has to be effected very carefully, and required in the old fashioned kilns as much as forty-eight hours, because the low temperature necessary could be secured only by slow combustion; this method was and always is a risky one. In the first stages of the drying of malt the temperature has to be kept very low; and in the vacuum apparatus therefore hot water, of which the temperature is easily regulated by a thermometer, is used instead of steam as the heating agent at the outset, while at the same time as high a vacuum as possible is created in the drying cylinders by an air-pump of special construction. In Figs. 5 to 7, Plates 59 and 60, is shown an air-pump consisting of a pair of vertical single-acting pumps P, worked from opposite ends of a crank-shaft, which is driven by a steam cylinder and controlled by a pair of heavy fly-wheels; it gives a vacuum of 29 inches of mercury. Even at so low a temperature as only 87° Fahr. or 30° Cent. vapour already rises from the malt and is carried off by the air-pump. After two hours' drying at this low temperature the malt is dry enough for steam to be used instead of hot water, without incurring the danger of overheating the malt and thereby forming inside the grains a hard or horny yellowish substance called glass-malt, which is unfit for the production of beer or alcohol, and displaces part of the soft powdery flour that otherwise constitutes the whole content of the grains. After another hour or two the malt is quite dry, the complete drying thus occupying only from three to four hours, instead of the forty-eight usually necessary in the old kilns. When dry a still higher heat is applied to the malt for a short time, in order to give it the appearance which it is considered good malt for brewing ought to possess. In some cases it would be practicable for a brewery which does its own malting to use apparatus of this kind in the hot summer months for the drying of beer grains, and during the winter for malting. But if the apparatus is intended to be used for malting only, a few modifications are advisable; and in most cases it pays better to dry the beer grains all the year round, because in a wet state they do not fetch a price approaching what they do after being dried. Wet grains can be given only to milch

cows or to cattle for fattening; whilst dried grains, being a splendid substitute for oats, can be given to horses and also to sheep &c., for which they have hitherto been unavailable.

At Messrs. Guinness's brewery in Dublin the Members had the opportunity at the last summer meeting of seeing the two machines there employed. In each of these the top cylinder is 20 ft. 4 ins. long and 2 ft. 8 ins. diameter, and the screw working inside it makes 7 revolutions per minute; the bottom cylinder is 19 ft. 2 ins. long and 5 ft. 4 ins. diameter, and the drum of tubes inside it makes 5 revolutions per minute. The drying surfaces of the two cylinders amount together to a total area of about 1,000 square feet, of which about 40 per cent. is heated by exhaust steam and 60 per cent. by live steam direct from the boiler. There is only one air-pump, which is made large enough for three machines; it is horizontal, and has only one air-cylinder, which is double-acting, $17\frac{3}{4}$ inches diameter and $17\frac{3}{4}$ inches stroke; and it is driven at about 45 revolutions per minute. As the result of about eight months' experience up to the beginning of the present year, the two machines were found to have been working quite satisfactorily, and to have been drying the wet grains from about 500 cwts. of malt per day of twenty-four hours, which is in excess of the estimated and guaranteed quantity.

Roughly speaking 3 cwts. of malt give 4 cwts. of wet grains, and the latter yield 1 cwt. of dried grains; 500 cwts. of malt will therefore yield about 670 cwts. of wet grains, or 335 cwts. per machine. The quantity of water to be evaporated from the wet grains is from 75 to 78 per cent. of their total weight, or say about 512 cwts. altogether, being 256 cwts. per machine. Instead however of obtaining only one-third of the malt in the shape of dried grains, the author often gets 38 per cent. or more, according to the system of brewing. While the value of grains before and after drying depends of course very much upon the local markets, the following figures are believed by the author to represent a fair average for this country:—wet grains fetch from 1*s.* 6*d.* to 1*s.* 9*d.* per quarter of mashed malt (3 cwts.), whilst dried grains are sold at from 4*s.* 6*d.* to 6*s.* 6*d.* and upwards per cwt., which represents about one quarter of mashed malt.

Grain damaged at sea can be dried by this apparatus with the greatest advantage and economy; as can also grain harvested in a wet season, and containing too much moisture to be stored at once, as is often the case with barley, oats, wheat, rye, &c., for which hitherto kiln-drying has had to be resorted to. In such cases the water only adheres externally, and is not contained within the grains themselves, as it is in brewery or distillery grains; it is therefore evaporated rapidly, and thus the drying capacity of the apparatus is largely increased. In general the quantity of water to be removed is not more than from 20 to 30 per cent. of the whole weight of the wetted material; hence an apparatus which evaporates 20 tons of water out of beer grains in twenty-four hours dries easily in the same time 200 tons of grain containing only 20 to 30 per cent. of moisture. Of course an alteration in the mode of charging and discharging becomes necessary, in order to render the drying process altogether continuous; and this is easily arranged by means of perforated revolving plates or discs, or other similar appliances.

The above examples are only a few of those in which this plan of drying can be applied with great advantage and with the best results. Chemicals also offer a large field, in which this method of drying in vacuum could be introduced with good effect.

Discussion.

Mr. William Strohn regretted that his partner, Mr. Passburg, had been unable to come from Breslau to attend the Meeting as the author of the paper.

Professor KENNEDY enquired what it was that gave the creeping action in the bottom cylinder for making the grain travel forwards from the back end to the front. The blades on the revolving drum seemed to be shown straight and parallel to the axis of the drum, instead of being set helically.

Mr. STROHN replied that no creeping action was required to be given by the drum in the lower cylinder. The grains when dry dropped into the discharge vessel D, Plates 56 and 58, and emptied themselves out of the cylinder without receiving any creeping action from the drum. The revolving action of the blades stirred the grains, and they formed a falling gradient from the back end of the cylinder towards the front, so that they were gradually pushed forwards by the pressure of the higher grains at the back end.

Mr. ROBERT BAELZ asked how the author had arrived at the price of the wet grains as given in page 314 from 1*s.* 6*d.* to 1*s.* 9*d.* The London price was about 2*s.* 6*d.*, which made a great difference. Some time ago Messrs. Guinness's price was £3 10*s.* per ton of dried grains, bags included; the bags cost at that time of the year about 12*s.* per ton, which would bring the price of the dried grains to £2 18*s.* per ton. The price of dried grains given in the paper, from 4*s.* 6*d.* to 6*s.* 6*d.* per cwt., would be from £4 10*s.* to £6 10*s.* per ton, while Messrs. Guinness supplied them at £2 18*s.* Being much interested in the machine, he should be glad to know what was the consumption of coal per ton of dried grains, and also how many workmen were wanted for charging and discharging the machine.

Mr. EDWARD B. MARTEN, Member of Council, wished he had paid more attention to this machine at the Dublin Meeting last summer, when the Members had the opportunity of seeing it at Messrs. Guinness's brewery, where he understood it was then working; and it would have been advantageous if the present paper, which had since been received, could have been read at a time when they could have seen the machine itself. Having now read the paper

with interest, he had been puzzled to understand why so apparent an advantage as that of drying in a vacuum should not have been adopted before. It was almost difficult to believe that this was the only apparatus ever used for the same purpose. Though in exactly the opposite direction, it almost seemed as great an improvement as Papin's digester had been for dissolving various materials under higher pressure and higher temperature. In the present case advantage had been taken of a vacuum for obtaining the evaporation at such a low temperature; and the adoption of so valuable a method had apparently had to await the time when a material had to be tried which would not bear a high temperature. No doubt drying in a vacuum had been employed before for liquids; but the difficulty with wet grains was that they formed an almost immovable solid when first put in, though when nearly dry the grain was movable enough, for it ran like liquid. He asked whether the author knew what other attempts had been made on the same principle; because it would be interesting to compare the results now described with what others had done. He should also like to know the kind of air-pump used in the apparatus, because the one shown in Plate 59 appeared from the mention made of it in the paper (page 313) to be only for drying malt; but he presumed it was something like the one for drying grains. Had the pump to take the whole of the vapour and pump it as vapour? or were there any means of condensing, so as to reduce the bulk that had to be pumped in order to keep up the vacuum? He also enquired whether in the lower cylinder there was any tendency for material not quite dry to stick and clog, as he should fancy that wet material would sometimes do. Did it never fasten on the hot tubes? or what cleared it away from them? He further wished to know whether the same principle had been applied to drying rapidly the sludge coming away from sanitary works, which seemed to be such a puzzle to sanitary engineers. It seemed strange that a principle which had been known for years had not been applied to so obvious a use.

Mr. Frederick Colyer said a plan of drying grains, which as far as he knew was somewhat similar to that now described, had

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been introduced into this country about twenty-three years ago; he had been consulted upon the matter and had had to do with the first experiments. The system had also been used in London for drying oats and damaged grains of different kinds, and had been successful in working. For malt drying a similar plan had been introduced by Tizard into this country about 1852; and he believed that twelve or fourteen years ago the Germans used a like plan, which he thought had been introduced there by Geemen.

The President asked whether it was the same identical plan.

Mr. Colyer said not precisely, but the same principle was involved. At the time he mentioned, twenty-three years ago, the grains dried by that plan had been analysed by the late Dr. Voelcker, who had reported most favourably upon it. The food was much liked by cattle, and in many cases they would leave other food to eat the dried grains. Although the plan had been a financial success in this country, the great difficulty to contend with had been that pointed out by the author, namely that there was something like 75 or 80 per cent. of moisture to be got rid of. The apparatus described in the paper he could quite understand would be a great improvement upon what had been done before; but he did not consider it entirely novel, at any rate in this country. The principle of an air-blast with heat combined had been applied by Mr. Gibbs of Gilwell Park, Essex, for drying wet fodder, oats, and other things (Royal Agricultural Society's Journal 1869, page 554).

The President enquired what was the kind of apparatus employed in that case.

Mr. Colyer could not give any detail with regard to Mr. Gibbs's plan, except that the material, whatever it might be, was dried over a perforated cone, and by means of a powerful blowing fan the heated air was driven through it. By an application of that principle about twenty or twenty-two years ago in a scheme in which he had been engaged, hay damaged by sea water had been rendered sweet

by driving the heated air through the mass itself. Another plan had been that of driving steam through it. In the author's statement that the grains should be dried at the brewery he quite concurred, because years ago it had been found that owing to the large percentage of moisture the carriage in getting the material away was very expensive, and materially reduced the profit arising from the grains. It was a mistake to suppose that the plan was entirely new in this country; it might be so in France.

Mr. Edward B. Ellington asked why it was that the system referred to by Mr. Colyer as having been in use twenty-three years ago had been given up. He supposed it was not in use at the present time, and there might have been some disadvantage connected with the particular kind of apparatus which prevented its success.

The President enquired whether the cause of failure had been the large quantity of moisture that had to be removed, amounting to from 75 to 80 per cent.

Mr. Colyer said that was partly the cause. The plan had not proved so profitable as had been anticipated, although there had been a good profit. The scheme he believed was carried on by Mr. Gibbs at the present time, though he had not himself had anything to do with it personally.

Mr. Joseph Tomlinson, Vice-President, considered Mr. Colyer's remarks were widely apart from the subject of the paper, because he was speaking of driving air through a mass of hay, whereas the plan described in the paper consisted in stirring the material by rotating arms, and turning it over and over in heated air or in contact with heated surfaces in a vacuum. The two methods were totally different. The plan described in the paper seemed to him to be a very natural method of proceeding, because the material was thereby kept perpetually moving, and was not allowed to remain stationary in contact with the drying surface, as would be the case in driving the air through it in the way described by Mr. Colyer. In

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the upper cylinder the grain was carried forward by the screw creeper, and in the lower by gravity, as explained by Mr. Strohn. It seemed to him to be a simple and proper way of getting all the surface of the grain exposed to the air and so drying it; and he considered it an admirable mode of getting rid of the moisture in grain, without requiring a higher temperature than 110° Fahr.

The PRESIDENT enquired whether the evaporation referred to by Mr. Colyer was direct from the material, without a current of air passing over it, or whether warm air was driven through the material.

Mr. COLYER explained that he referred to two different plans of drying, in one of which a current of heated air was driven through the material, while the other was a plan somewhat like that described in the paper. As compared however with what had been done before, the apparatus now described was a considerable improvement for the drying of brewers' grains; the application to fodder, which he had previously mentioned, was a minor consideration. Apparatus of like kind had also been used for granulating or drying sugar and other materials.

Mr. DRUITT HALPIN enquired how it was that with the air-pump shown in Plate 59 so great a vacuum could be obtained as that stated in the paper of 29 inches of mercury. The barometer could not be much over 31 inches; and he should hardly expect to get such a vacuum from a pump of that kind with such large clearances as it appeared to have.

In the lower cylinder of the drying apparatus the revolving drum of tubes resembled what was called a reel in the old Wetzel plan of drying sugar. The great trouble experienced in that case had been that the tubes were always leaking, as might be expected, on account of their own weight and the torsional strains upon them; and notwithstanding that the apparatus was never wanted to be worked at more than exhaust pressure, it was always giving a great deal of trouble by leakage. In 1871, in conjunction with Mr. Alliott, he

had devised a plan for getting rid of all that trouble, by simply carrying the shaft right through the whole length of the drum or nest of tubes; and on each end of the shaft was secured a hollow disc of gun-metal or cast-iron, forming a steam-chest, into which the tubes were fixed by expanding their ends with an expander. Into one steam-chest the steam entered through the hollow shaft, and from the other it was similarly exhausted. When tested with steam at 100 lbs. pressure there was no leakage, because there was no torsion on the tubes and no sagging.

Mr. Henry J. Worssam thought a defect of the apparatus described in the paper was the smallness of its capacity. From what he knew of the requirements of one of the ordinary London breweries he calculated that eight of these machines would be wanted; they would weigh altogether about 128 or 130 tons, and the cost would necessarily be great. For malting, the plan seemed to him to be entirely out of the question, because any maltster would say that the fact of not being able to examine the material while it was being dried would render the apparatus quite useless, inasmuch as in the course of malting it was often required to stop the process of drying almost instantly. A small leakage would seriously spoil the effect of the air-pump; and this leakage would be very likely to occur, owing to the inlet and outlet valves having to be opened every two hours.

With regard to the price of dried grains, he believed that those of Messrs. Guinness fetched about £3 or £3 10*s.* per ton. If all the brewers dried their grains, a much lower price might be looked forward to. Then again brewers had to take into consideration the question of storage; they could not sell all their dried grains during the summer; and he knew that one comparatively small brewery, where the grains were dried, had in October last as much as 80 or 100 tons of grains lying in store for sale. In a large London brewery there would no doubt be eight or ten times as much on hand, which would be rather a serious matter, considering the high rentals paid in London. The price of grains in London at present was 2*s.* or 2*s.* 3*d.* a quarter as they lay in the mash-tun; the

(Mr. Henry J. Worssam.)

brewer did not take them out; that was done by the contractor who purchased the grains. So that in drying, the cost of conveying the grains from the mash-tun to the machine had to be taken into consideration. There was also another question as to the repairs of the machine, which he understood were a serious item, in consequence of the grains becoming acid, and causing the wrought-iron to corrode rapidly.

Mr. Baelz said that brewers' grains were contracted for all the year round, and if they were not taken away they were paid for all the same; so that a London brewer had no necessity to dry the grains, because he could get rid of them in the wet state, and get his money for them immediately. Mr. Gibbs's mode of drying which had been referred to had not proved a success, because it did not dry the material uniformly throughout; it had been used he believed for cement and other articles, but for drying wet grains it had not been a success; the drying was not done in a vacuum. A machine for drying grain had he believed been put up in London by Messrs. Milburn of Commercial Road, which appeared to him to be in some respects similar to that described in the paper, but somewhat differently arranged. It consisted of an inside cylinder with steam-jacket, which was surrounded by an outside cylinder also steam-jacketed; the inside cylinder revolving turned the grains over both inside itself and also in the outer cylinder; the great defect was that it did not get rid of the moisture sufficiently. There were in Commercial Road twenty machines of that kind drying grains every day. The apparatus described in the paper he believed would be found to be very expensive.

Mr. Thomas Browning, representing Messrs. Milburn and Co., said the machine described in the paper seemed to him to be similar to one that had been used for many years, having been made by Messrs. Davey Paxman and Co. twenty years ago, but with the difference that the vapour had been got rid of by exhausting it either by a flue or by a fan (Royal Agricultural Society's Journal 1869, page 556). Many plans of drying grains had been devised, but

there had been difficulties in the way of their success. He had had to do with drying grains since 1865, since which date there had been one continual drying and one continual success, and at the present time Messrs. Milburn were drying at the least 2,000 quarters of grains a week. They were drying the whole of the grains from the City of London Brewery, and part of the grains from Messrs. Truman and Hanbury's and other breweries. Messrs. Guinness's grains in Dublin had also been dried for ten or twelve years by Milburn's machines.

The President enquired whether in those machines the exhausting flue or fan produced a partial vacuum in a closed chamber; or did it draw a current of air over the grains?

Mr. Browning replied that the latter was the case; the exhaustion did not produce a vacuum beyond that requisite for causing the air to follow after the fan.

The President said that was a great difference from the air-tight vacuum chamber in the present machine.

Mr. Browning, in explanation as to how the grains travelled horizontally along the machine, said they were of course larger in bulk when wet than when dry, and therefore stood higher in the drying cylinder at the wet end than at the dry end; the difference of level consequently caused them to move along towards the dry end of the cylinder.

There was a great deal of wear in grain-drying machines, and the acid from the grains acted rapidly on wrought-iron; it had not the same effect on cast-iron, but the wrought-iron tubes of the drum shown in the drawings he was of opinion would be destroyed in a short time. Judging from his own practice there were also likely to be many leakages from the discs in which the tube ends were fixed; and from disc to disc there would be a certain strain and certain inequalities in expansion and contraction. Without wishing to discourage the plan described, he believed there would be

(Mr. Thomas Browning.)
considerable trouble and great expense in keeping those joints perfectly tight and in working order.

With regard to the price of the wet grains, the price of what were called beer grains was 1*s.* 6*d.* per quarter, and of ale grains 2*s.* 3*d.*; these prices did not include cartage, but were the absolute prices received by the brewer for the wet grains in the mash-tun.

Mr. JOHN R. FOTHERGILL thought that in a vacuum, in the absence of air to accelerate rust, corrosion would not be so important and destructive as it would be when working in the open air. And if there were corrosion, might not the tubes be made of thin copper coated with zinc? This he considered would not be a matter of any serious expense.

Mr. ARTHUR PAGET, Vice-President, understood that, apart from priority of invention of which the Institution took no cognizance, the principle of the machine described in the paper was that air was not drawn over the grain in any way, but was drawn *out of* the grain, because the whole drying process was done in vacuo; and the fact had now been elicited that no other of the processes mentioned during the discussion had been carried on in vacuo. There could be no doubt that for many processes of drying there were advantages in this machine over the machines which did the work by drawing air over the material instead of merely heating it in vacuo. With regard to the passage of the grain from the back end of the lower larger cylinder to the front end, it was usual to talk of a water level or a water gradient, and he did not see why the same expressions should not be used for the grain. The front end he presumed would never be full of grains, but the grain line would always slope downwards from the back end to the front. Would not that have another effect, namely that the grains would thereby be prevented from adhering to the revolving drum of tubes?

Mr. A. H. MURE asked if it was known whether cow-keepers, to whom a large quantity of grains went for the production of milk, considered that one ton of dry grains would produce the same

amount of milk as an equivalent weight of 3 to 4 tons of wet grains. Cow-keepers wanted quantity: they were not always careful about the quality of milk produced.

Mr. TOMLINSON said that was hardly a matter which concerned the machine. If cattle ate dry grains they would require water; in wet grains they got the two mixed.

Mr. WILLIAM ANDERSON, Vice-President, considered the machine was well adapted to the particular purpose for which it was constructed, namely to dry in vacuo. A good deal of information on drying would be found in the Journals of the Royal Agricultural Society, who had had two if not three competitions with machines for drying crops. Those competitions had shown that for agricultural purposes at any rate it was impracticable to use artificial means of drying, the cost being too great. The competitors seemed for the most part to have been led away with the idea that if they employed a fan, or agitated the corn or hay or grass sufficiently, a pound of coal could be made to evaporate more water than by its thermal capacity it was capable of doing, namely about 13 or 14 lbs. of water per pound of coal; and consequently had always regarded as trifling the expense of the fuel necessary for converting into vapour the large proportion of water which some crops contained, and which had to be driven off in order to dry them. But when those plans came to be put to the test of experiment, it was found that the cost of the fuel was altogether prohibitive of the use of apparatus of the kind. That was the reason why he thought he might say that, with few exceptions in particular cases, artificial drying had been completely abandoned. Even apparatus for drying comparatively costly things like fruit had been given up. Last year a trial had been made of an apparatus which had been sent over from the Continent for drying fruit; it was simple and ingenious, made of wood and costing but little; but it did not prove acceptable, because farmers who wished to dry their fruit could put it into baskets, and dry it in their own ovens. There was therefore little prospect he thought of drying crops artificially, except under special

(Mr. William Anderson.)
conditions. All who had had to do with drying vegetable matters knew very well that a low temperature was necessary, if they wished to be sure of not injuring the constitution of the material. For this reason he conceived that drying in vacuo would yield a higher quality of product than could be obtained by drying at atmospheric pressure and temperature; but whether at a less cost he did not know.

Mr. W. T. HARRIS, of the City of London Brewery, said he attended for the purpose of getting information as to what could be done by drying in vacuo: the plan appeared to him to be a move in the right direction.

Mr. CHARLES SEVIN said the only interest he took in the matter was as a dealer in the grains. The selling price of dried grains was considerably less than that stated in the paper of £4 10*s.* to £6 10*s.* per ton; he should say from £4 to £4 10*s.* The average cost price of wet grains had been 2*s.* 3*d.* per quarter during the last year.

Mr. GEORGE A. MOWER enquired whether it was a fact, as stated in the paper (page 310), that the nutritious qualities of the material to be dried would be seriously impaired by the use of a temperature of about 212°. The paper seemed to imply that the grain-drying industry was a comparatively new one; and also that the drying machines in use at the present time had not been successful. Yet one firm in Germany had supplied 130 drying machines for use in that country, a dozen or more in Austria, and twenty in America. There was a large business in drying grains in London; in one instance that he knew of, an agreement had been entered into for supplying 9,000 tons of dried grains, which would involve the working of three of the machines described in the paper for about a couple of years.

The PRESIDENT asked whether the machines referred to as so extensively in use in Germany were working at a higher temperature than that described in the paper.

Mr. Mower replied that they were working at a much higher temperature than 212° Fahr., and that their product was of excellent quality. The machines described in the paper had been introduced he believed some two years or more, and he should be glad to know how many of them were now in use. These machines had been spoken of in the paper as being the first application of drying solids in vacuum; but when in Norway last summer he had himself been informed that it was the common practice there to dry timber in an air-tight wrought-iron chamber, heated by steam, to which an air-pump was connected for maintaining a vacuum and removing the moisture; similar timber-drying chambers he had also been informed were used in Germany. He enquired the cost of the author's machine, in order that the interest on capital might be taken into account. He should like to know something of the cost of fuel, labour, and repairs; for in the paper had been given only an estimated value of the wet grains and the selling price of the dried grains; and nothing had been mentioned as to the cost of drying the grains, either in pounds of exhaust steam or in pounds of live steam or in pounds of coal.

Mr. Strohn, in reply, said the statement given in the paper, that the price of wet grains was 1*s.* 9*d.* per quarter, had been made on the authority of Messrs. Combe and Messrs. Mann and Crossman, who had informed him that the average price during the year was 1*s.* 9*d.*, but it was sometimes 2*s.* 6*d.* and sometimes much less. With regard to the drying expenses, it might be taken that one pound of steam evaporated one pound of water in this apparatus. What it would cost to raise that one pound of steam depended on the boiler and on the coal used. If the steam-generating power of the coal were known, and also the loss in the pipes &c., it would be known exactly how much coal was required for drying.

The use of a vacuum for drying was not claimed as a new thing, but only the arrangement and construction of the apparatus for enabling advantage to be taken of the vacuum with commercial success. The object was to get as large a heating surface in as small a vessel as possible. The application of the vacuum might

(Mr. William Strohn.)

possibly be met with in other plans; but he did not know of any other vacuum apparatus having been used for drying solid materials. The mere use of exhaust or any sort of suction was not vacuum, as long as the air entered the chamber from which the suction drew. It was only when a chamber closed air-tight was used with a high vacuum that the advantages of drying in vacuo were realised; as soon as the vacuum fell for instance as low as 20 inches of mercury, it became no longer worth while to use an air-pump at all.

As to the grains sticking upon the heating surfaces, it would be observed that the upper cylinder contained a cast-iron creeper and no tubes, whilst it was only in the lower cylinder that there were tubes. The tendency of the wetter grains to stick was the reason for employing the cast-iron creeper in the upper cylinder, in which there was very little room between the tube or body of the creeper and the sides of the cylinder, so that the grains themselves kept the cast-iron tube clean; whilst by the time that they had passed through the upper cylinder and dropped into the lower, sufficient moisture had already been evaporated to render them incapable of sticking any more. Anything like a grain level or gradient could hardly be said to exist in the lower cylinder, except in imagination prompted by the practical result realised; for it should be understood that the grains in the lower cylinder were being continuously lifted by the blades attached to the slowly revolving tube-drum, so that there was no actual grain level: the grains were not in any regular layer over the cylinder, but were lifted and dropped and lifted again.

So high a vacuum as that mentioned in the paper of 29 inches of mercury was by no means difficult to obtain; and no air-pump was accepted which did not show a vacuum of at least 28 or $28\frac{1}{2}$ inches. All the moisture drawn off from the drying machine was purposely condensed before it reached the air-pump, by means of an intervening jet condenser of the kind shown in Fig. 8, Plate 60, consisting simply of a long vertical tube, through which the vapour entering at the top passed downwards, being condensed in its course by transverse jets of water issuing from a central perforated copper pipe. Nothing but water was accordingly drawn off from the bottom of

the condenser by the air-pump, which was thus a wet air-pump and consequently free from loss due to clearance. It was a jet condenser of this kind that was used at Messrs. Guinness's brewery.

As far as leakage was concerned, if the apparatus was constructed properly and the tubes properly fitted in, there was no leakage. During three years' working of these machines he had never found any new leakage arise. Although no machine was absolutely perfect in that respect, yet he believed Messrs. Guinness, who had had their apparatus working for ten months, had not had a single leakage; and he had never heard of any leakage occurring in the apparatus that had been supplied to other breweries; so that he thought there could not be any undue expense for repair.

As to the question of price, if the apparatus was properly built with good material and first-class workmanship, it was by no means cheap in first cost; but as it was built to dry 500 cwts. of malt in twenty-four hours, it would prove decidedly cheap in the long run. The two machines put up at Messrs. Guinness's brewery were drying the same quantity of wet grains as the plant of Messrs. Milburn which consisted of sixteen machines. Undoubtedly each of the latter was cheaper; but multiplying its cost by sixteen they would be found dearer than the two machines described in the paper. The cost of the two machines at Messrs. Guinness's was about £600 each; and since their erection the construction had been considerably improved, so that new machines of no higher cost would now do more work. As to the price of the dried grains, it had been mentioned that Messrs. Guinness sold their dried grains at £3 10*s.* per ton, and he had known them sell for over £4 per ton. For an apparatus of the size there employed two men were enough for filling and emptying and for attending to the air-pump; and if the engine was combined with the air-pump they could attend to that also, and would still have sufficient spare time to attend to the sacking of the produce; besides these two men there was one boiler-man. Messrs. Guinness he believed were working their two machines with three men.

The application of the apparatus to the drying of sludge had been considered, but he believed it would scarcely cover the expense of evaporating the large quantity of water, which amounted to as much

(Mr. William Strohn.)
as about 97 per cent. Moreover as the stuff dried he supposed it would clog the apparatus.

Corrosion arising from acid in the grains would no doubt be a great objection; but a brewer would take care not to let the grains turn sour and so create the acid to spoil the apparatus. Fresh grains contained no acid whatever when they came from the mash tun. If they became acid, any metal would suffer; he did not see that the vacuum would prevent that.

The PRESIDENT asked how many of the machines were now in use; and whether the grains were really damaged at a temperature above 212° Fahr. when quick evaporation by boiling was employed for drying them.

Mr. STROHN replied that there were now ten machines in use. As to the other question, it was undoubtedly more advantageous to dry the grains at as low a temperature as possible, which was confirmed by Mr. William Virtue, of Crosswell's Brewery, Oldbury; and the same opinion had been expressed also by Mr. Allen, the President of the Society of Public Analysts. Although he could not himself say that the grain would be damaged at a higher temperature, he supposed that this was what was meant to be inferred. In the drying of malt it would be even more important to avoid a high temperature, for the reason mentioned in page 313 of the paper.

The PRESIDENT was sure that, after the discussion to which the paper had given rise, it would be safe to come to the conclusion that this apparatus did at any rate get rid of the objections which had been referred to; and that it was a machine which really did dry in vacuo. The point fairly claimed for it was the successful application of drying where no air was heated, but a simple evaporation of the moisture from the solid material took place; and in this respect he thought that the author had established, he would not say the originality of the principle, but a new application of it. The Members he was sure would all join in thanking him for

having brought the subject before them, and for giving the brewers of this country something to think about, as to whether it was worth their while to follow the example which had been set them by Messrs. Guinness of Dublin.

MEMOIRS.

James Davidson was born at Dee Village, Aberdeen, on 11th May 1819. The school education he received was very slight, as he started work at the age of nine in a brick field. When about fourteen years old he was apprenticed to Messrs. Hadden and Co. at Grandholm Mills, near Aberdeen, which were then being worked as flax mills. He had previously been employed for a year or two at Messrs. Blaikie Brothers, Footdee Iron Works, Aberdeen. In 1845 he went to Glasgow, where he was employed as a mechanic at the works now carried on by Messrs. Napier and Sons. During his apprenticeship and while working at Glasgow he tried to make up for his lack of education by availing himself of all the means in his power for increasing his knowledge of the theory of mechanics. Early in 1846 he moved to London, and obtained work at Messrs. H. and O. Robinson's, Millwall. On 17th September of the same year he left them to enter the Royal Arsenal, Woolwich, having been offered employment there by Mr. Anderson, who was then in charge of the Dial Square, Royal Gun Factory. Here he was engaged in carrying out Mr. Anderson's idea of forming conical lead bullets from the rod by machinery, and it was largely owing to his mechanical skill that these bullet-making machines were so successful. About 1853, when the machines were transferred to the laboratory department, he went with them to superintend their working. Shortly afterwards, at a time of great emergency, he was chosen by Capt. Boxer to aid in establishing and working what was then known as the "temporary factory." In 1855 he was appointed manager of the Royal Laboratory, in conjunction with Mr. Tozer, who was in charge of combustible stores. On the retirement of the latter in 1871 he became sole manager; and this position he held up to October 1885, when he retired, after a service of nearly forty years, thirty of which had been as manager. He died on 4th March 1889, after only a week's illness, in the seventieth year of his age. He became a Member of this Institution in 1865.

Amongst the inventions and improvements due to him may be mentioned the present pattern of machine for making conical bullets, which is more compact than the old machines, and turns out the bullets at a much quicker rate; also machines for rounding the head and canneluring the bullets; and machines for punching and cupping four cups at once for the base cups in Snider and Martini cartridges; in fact a large portion of the machinery employed in the manufacture of the Snider and Martini rolled cartridges may be ascribed to his inventive mechanical skill (Proceedings 1868, page 129). The method of chilling the heads of cast-iron Palliser projectiles is also due to him. Indeed the laboratory department itself affords ample evidence of his mechanical and administrative ability.

Edwin James Grice was born in Westbromwich in 1834, and died at his residence, Beechwood, Reigate, on 9th March 1889, at the age of fifty-five. His father was a manufacturer of screws and gun implements at Overend Works, Westbromwich; and early in 1852, when fish-plates for railway joints came into general use, he commenced the manufacture of fish-bolts and other railway accessories. The son very early in life showed great mechanical aptitude, and with his elder brother, the late Mr. Frederick Groom Grice, invented valuable machinery for the manufacture of bolts and nuts. In 1855 their father entered into partnership with Mr. Joseph D. Weston, under the style of Weston and Grice, and erected large new works at Spon Lane, called the Stour Valley Works, of which the two brothers took the management. Under their superintendence improved machinery was introduced whereby considerable economy was effected in the manufacture of bolts and nuts and other railway fastenings; and the business increased so rapidly that further extensions of the works became necessary. In 1862 therefore the firm purchased the Cwm Bran Works, Newport, Monmouthshire, which have since been largely extended and developed. About that time both brothers were taken into partnership, and Mr. Edwin James Grice became manager of the Stour Valley Works, and his brother of the Cwm Bran Works. In 1864 the whole of the works

were taken over by the Patent Nut and Bolt Company, of which the brothers were appointed managing directors. Upon the death of Mr. F. G. Grice in 1881 (Proceedings 1882 page 8), Mr. Edwin J. Grice was appointed managing director of the Cwm Bran works, collieries, and furnaces, which office he continued to hold until the end of 1887, when he was obliged to retire on account of ill health, but still retained his position as director of the company. He was a magistrate for the county of Monmouth and for the borough of Newport for several years. In 1884 he was elected mayor of Newport, and in the same year he was appointed High Sheriff and Deputy Lieutenant of the county of Monmouth. He became a Member of this Institution in 1866.

EDWARD ALEXANDER JEFFREYS was born at Shrewsbury on 20th August 1824, being the son of Mr. William Jeffreys, solicitor of that town. At the age of fourteen he was sent as apprentice to the engineering firm of Messrs. Bury Curtis and Kennedy, of Liverpool, where he was principally employed in making the plans of locomotive and marine engines, and afterwards in superintending their working. In 1845 he obtained the appointment of locomotive superintendent on the Shrewsbury and Chester Railway, being employed for the first fourteen months in superintending the construction of the rolling stock. This appointment he held for eight years until the line was absorbed by the Great Western Railway. In 1853 he was engaged by Mr. Thomas Brassey to go out to Canada as locomotive superintendent of the Grand Trunk Railway; but upon the opening of the Shrewsbury and Hereford Railway, Mr. Brassey appointed him to manage and work that line for him during his lease, which he did until its termination. In 1863 he obtained the appointment of general manager of the South Eastern of Portugal Railway, but after a few months relinquished it on being offered the position of consulting engineer and representative to the Low Moor Iron Works. This position he filled until he was offered a partnership in the Monk Bridge Iron Works in July 1879, of which he became afterwards a director when the works were converted into a limited company. Having a very

extensive acquaintance with railways, he was regarded as an authority in matters of railway engineering. He died after a short illness at his residence, Hawkhills, Chapel Allerton, Leeds, on 3rd April 1889, at the age of sixty-four. He became a Member of this Institution in 1856.

John McConnochie was born on 9th October 1823 at Port Patrick, Wigtownshire, where his father was then engaged on the harbour works under Sir John Rennie. He was educated at the local school and at the Andersonian University, Glasgow, with a view to becoming a civil engineer, and his training commenced by his being placed for a short time to work in a mason's yard. For mechanical engineering he was then apprenticed to Messrs. Robert Napier and Sons, Glasgow; and acted for a short time as engineer on board the steamer running between Ardrossan and Belfast. He was next placed in the office of Mr. Thomas Kyle, engineering surveyor, Glasgow, whence he was transferred in 1846 to that of Messrs. Walker Burges and Cooper, London, by whom he was sent as assistant resident engineer to the government harbour works at St. Catherine's Bay, Jersey. There he remained until 1855, with the exception of one season when he was sent to assist Mr. Nicholas Douglass in the erection of the Bishop Rock Lighthouse on the Scilly Islands. In 1855 he went to Cardiff as resident engineer for Messrs. Walker Burges and Cooper on the extension works of the East Bute Dock; and on the death of Mr. James Walker in 1862 he was appointed chief engineer of the Bute Docks, which position he retained during the rest of his life. He designed and carried out the Roath Basin, Roath Dock, and many contingent works at the Bute Docks, of which he presented descriptions to this Institution in his papers read at the Cardiff Meetings in 1874 and 1884 (Proceedings 1874 page 119, and 1884 page 227). In conjunction with the Marquis of Bute's managing trustee, Mr. John Boyle, he had the satisfaction of seeing and providing for the extraordinary growth of the trade of the port of Cardiff, to the interests of which he may truly be said to have conscientiously devoted the best part of his life. His long experience led to his

being frequently consulted on dock matters. In 1880 he was elected mayor of Cardiff, and subsequently an alderman of the borough and justice of the peace. His death occurred from heart disease on 28th March 1889 in the sixty-sixth year of his age. He became a Member of this Institution in 1872.

Robert Stirling Newall, F.R.S., was born at Dundee on 27th May 1812. He first entered a mercantile office, but afterwards went to London, where under Mr. Robert M'Calmont he found more genial employment in connection with experiments on the rapid production of steam. In 1840 he invented a method of making wire rope by machinery, and established works for the purpose at Gateshead; and wire ropes of his construction are now used all over the world. From time to time he improved on the original design, and so lately as 1885 he devised a new machine by which the rope is made at one operation, thus avoiding the double process of first making the strands and then combining them into the rope. His interest in wire-rope making however was not confined to the gradual development of his earlier inventions. He was quick to see that wire rope might help in solving the difficulties which had to be overcome before submarine telegraphy could become an accomplished fact. The cumbrous devices at first suggested for protecting the outer covering of the cables were forgotten when he proposed in 1850 that the gutta-percha lines containing insulated wire should be surrounded with a strong wire-rope. The first successful cable between England and the Continent, from Dover to Cape Grisnez, was manufactured by him on this plan of wire protection, and was laid by Mr. Crampton on 25th September 1851 (Proceedings 1888, page 438); a previous cable not so protected had failed after one day's trial. In 1852 his firm manufactured the Holyhead and Howth and Port Patrick cables; and in 1853 the Dover and Ostend, the Firth of Forth, and the Holland cables. In 1853 he introduced a drum-brake for laying cables in deep seas, which, though for a time abandoned, has since been again employed. During the Crimean war, in November 1854 his firm laid a wire insulated in gutta-percha without sheathing of any kind from Varna to Balaclava;

the cable was run out over the stern of the vessel through hand leathers held by the cablemen in turn. In 1855 he laid the Black Sea cable between Eupatoria and Constantinople; and in 1859 and 1860 the Red Sea cable from Suez to Kurrachee. After laying the latter he was wrecked in the P. and O. steamer "Alma," and formed one of the boat's crew that left to seek help for the passengers. He devoted much of his time to scientific work, and had an observatory fitted up, for which he had a 25-inch refracting telescope constructed, the largest previously having had a 15-inch aperture; just before his death he offered this instrument as a gift to the University of Cambridge. He was twice mayor of Gateshead, and gave much time to local matters. He died at his residence, Ferndene, Gateshead, on 21st April 1889, in the seventy-seventh year of his age. He became a Member of this Institution in 1879.

RALPH PEACOCK, of Goole, was born at Fremington, in Swaledale, Yorkshire, on 6th September 1826; and his father removing shortly afterwards to Leeds, he commenced work at the age of eleven under him and his grandfather, who were the contractors for making the old Leeds tunnel on the Leeds and Selby Railway. He was apprenticed at York to Mr. Thomas Cabry, but was transferred to Selby, and before he was of age was sent to France to superintend some engineering works. On his return, his uncle, Mr. Richard Peacock, who was then locomotive superintendent of the Manchester Sheffield and Lincolnshire Railway, wished him to join that line, and he was appointed superintendent engineer at New Holland. He was transferred thence to Sheffield, and at the age of twenty-three was removed from the locomotive department to become marine inspector and manager at New Holland. Here he first became acquainted with Goole, having designed and prepared the specifications of the steamer "Cheviot" for Messrs. H. T. Watson and Co. Shortly afterwards he removed to Goole, and joined Mr. H. T. Watson in the Cyclops Engineering and Shipbuilding Works on the north side of the Barge Dock, of which he became the sole proprietor on the retirement of Mr. Watson in 1860. To meet the requirements of increasing business, the works were gradually enlarged until they extended

from the Barge Dock to the Lancashire and Yorkshire Railway; and the manufacture of smoke-consuming appliances, steering gear, and disintegrators, kept a large number of men in constant employment. Shipbuilding of all kinds was carried on, including many tugs, flyboats, and steam compartments for the Aire and Calder Navigation, and a large iron steamship, the "Mary West," of such a length that it had to be launched broadside into the Barge Dock. In 1867 additional works on the opposite side of the dock were purchased, and larger contracts were taken for engines, boilers, and shipbuilding, until in 1873 the whole business was converted into the Goole Engineering and Shipbuilding Company, Mr. Peacock retaining a large interest and acting for a few years as manager. On leaving this position, he bought a colliery in South Wales, which resulted in disastrous loss, for after the first few days the pit was flooded. Returning to Goole, he first took a wine and spirit business, besides acting as consulting engineer for the Yorkshire Coal and Steamship Company, in whose vessels he introduced many improvements of his own, including a propeller which was extensively adopted. The collision by which the "Cuxhaven" was sunk on 20th April 1886 did much to undermine his health, in consequence of the unremitting attention he bestowed upon the wreck for some days. Lately he had been occupied in the inspection of a new steamer building at Messrs. Earle's yard at Hull. He died on 29th April 1887, in the sixty-first year of his age. He became a Member of this Institution in 1869.

The Hon. WILLIAM RUSSELL was born at Myreside, Elgin, on 13th March 1827, and died in Georgetown, Demerara, on 28th March 1888, at the age of sixty-one. During his residence of forty-two years in British Guiana he was closely connected at one time or another with nearly every sugar estate in the colony, his opinion being highly valued by all planters, by whom he was colloquially styled the sugar king. Amongst the mechanical improvements with which his name is chiefly associated is that of macerating and double-crushing the sugar cane, which thus far does not appear likely to be superseded by the new diffusion process. Perhaps however his chief

claim to the gratitude of his fellow colonists was the elaboration of a system of water supply for the principal districts under cultivation, including also the city of Georgetown and the populous villages of the east coast. The government of the colony has voted a large sum of money towards the erection of a statue in his memory, the first instance on record of such a testimonial to the worth of any public man in British Guiana. He became a Member of this Institution in 1878.

Charles Reboul Sacré was born in London on 4th September 1831, and at the age of fifteen was an articled pupil under Mr. Archibald Sturrock upon the Great Western Railway. After serving his time he occupied a responsible position upon the Great Northern Railway at Boston and Peterborough. He was next engaged as chief engineer upon the Manchester Sheffield and Lincolnshire Railway; and was also connected with the South Yorkshire Railways, the Cheshire Lines Committee, the Humber Conservancy, and the Manchester South Junction and Altrincham Railway. During his several years' service in these capacities, he was continually engaged as engineer of the various new works in connection therewith, and also in giving evidence for parliamentary committees. His engineering ability with his acknowledged common sense in all matters of moment gained him a considerable reputation. The results in respect to the working expenses of the locomotive, carriage, and permanent way departments under his control showed notable success in the savings effected. In 1885 he retired from the Manchester Sheffield and Lincolnshire Railway, but was retained as their consulting engineer; and was engaged by several other railways to give evidence in connection with parliamentary arbitration and other matters. He became a Member of this Institution in 1859. His death took place in Manchester on 3rd August 1889, in the fifty-eighth year of his age.

George Spencer was born at Brighton on 17th June 1810, and at an early age attended the engineering classes at the Birkbeck Institute. Subsequently he worked in the drawing office of Mr.

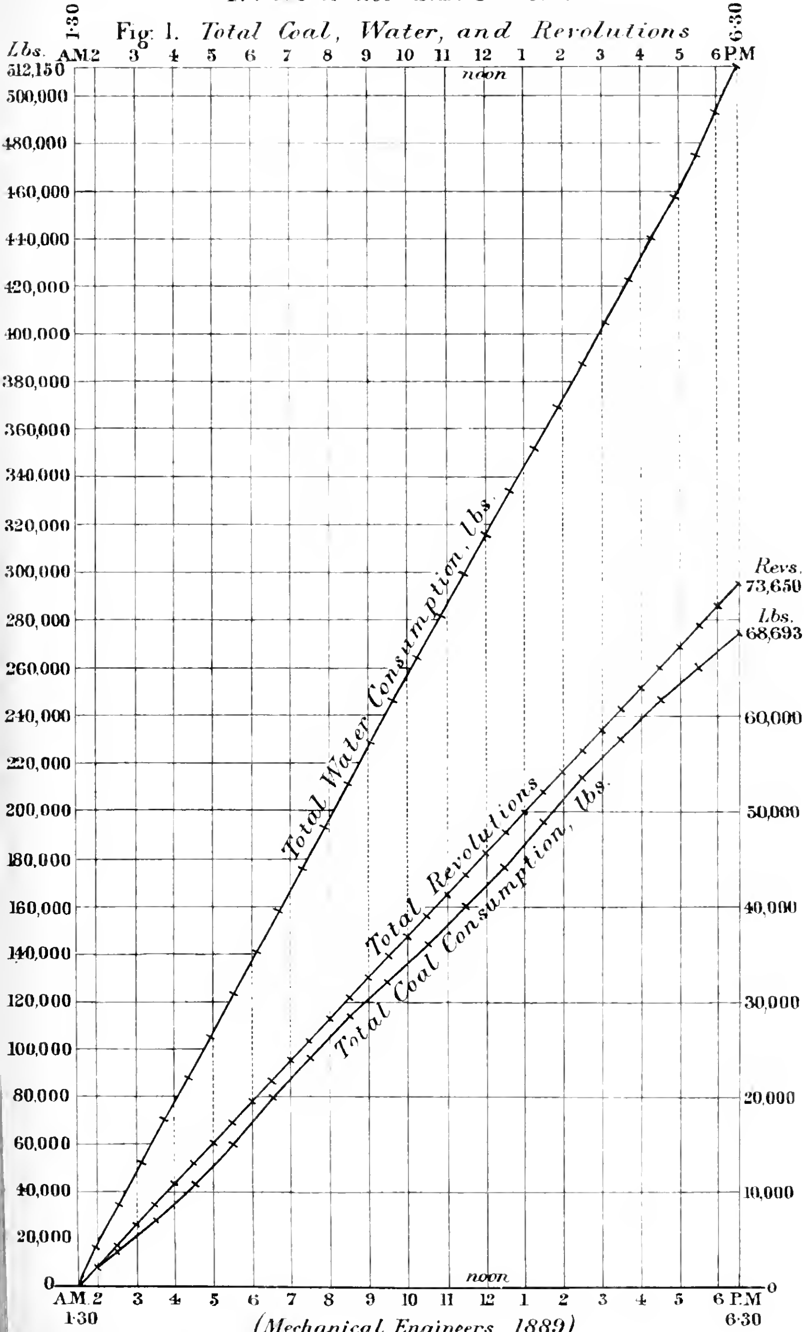
George Dempsey, and during the great extension of the railway system throughout the country from 1845 to 1848 was largely engaged in surveying. Afterwards he was employed by Messrs. Fox Henderson and Co. in assisting in the design and erection of bridges and roofs, and in the design of railway rolling stock. Amongst the many works with which he was connected under them were the Crystal Palace, of which he executed the drawings, and the Bricklayers' Arms Goods Station of the South Eastern Railway, of which he superintended the erection. In 1852 he founded the business of Messrs. George Spencer and Co. for supplying railways with india-rubber springs &c., in which he introduced several improvements that have been extensively adopted. He died at Montreux in Switzerland on 5th June 1889, in his seventy-ninth year. He became a Member of this Institution in 1878.

Robert Paulson Spice was born in Norwich on 1st January 1814. Having started in business as an ironmonger at Fakenham in Norfolk, his connection with the management of gas undertakings began with the construction in 1843 of the works for lighting that town. He then settled at Richmond, Surrey, where he devoted himself to the management of gas works under leases, according to a common practice at that time. In 1860 he opened offices in Cornhill, London, and for several years subsequently was lessee of the gas works at Wandsworth, Hampton Court, Richmond, and Watford. He also built gas works at Great Yarmouth, Boston (Lincolnshire), Tunbridge Wells, Tattershall, Abingdon, Hartley Wintney, Hoddesdon, and other places. The new works at Riddings, near Alfreton, have also just been completed from his plans. In addition to the work of construction, his services as adviser, witness, or umpire were constantly sought; and he had an extensive parliamentary practice. He was at one time interested in experiments for the manufacture and supply of water gas, and described the plan in June 1875 in a paper read before the British Association of Gas Managers, of which he became president in the following year. The plan was tried on a working scale at the Crystal Palace District Gas Works, but proved unsuccessful. In 1881 he was concerned with the

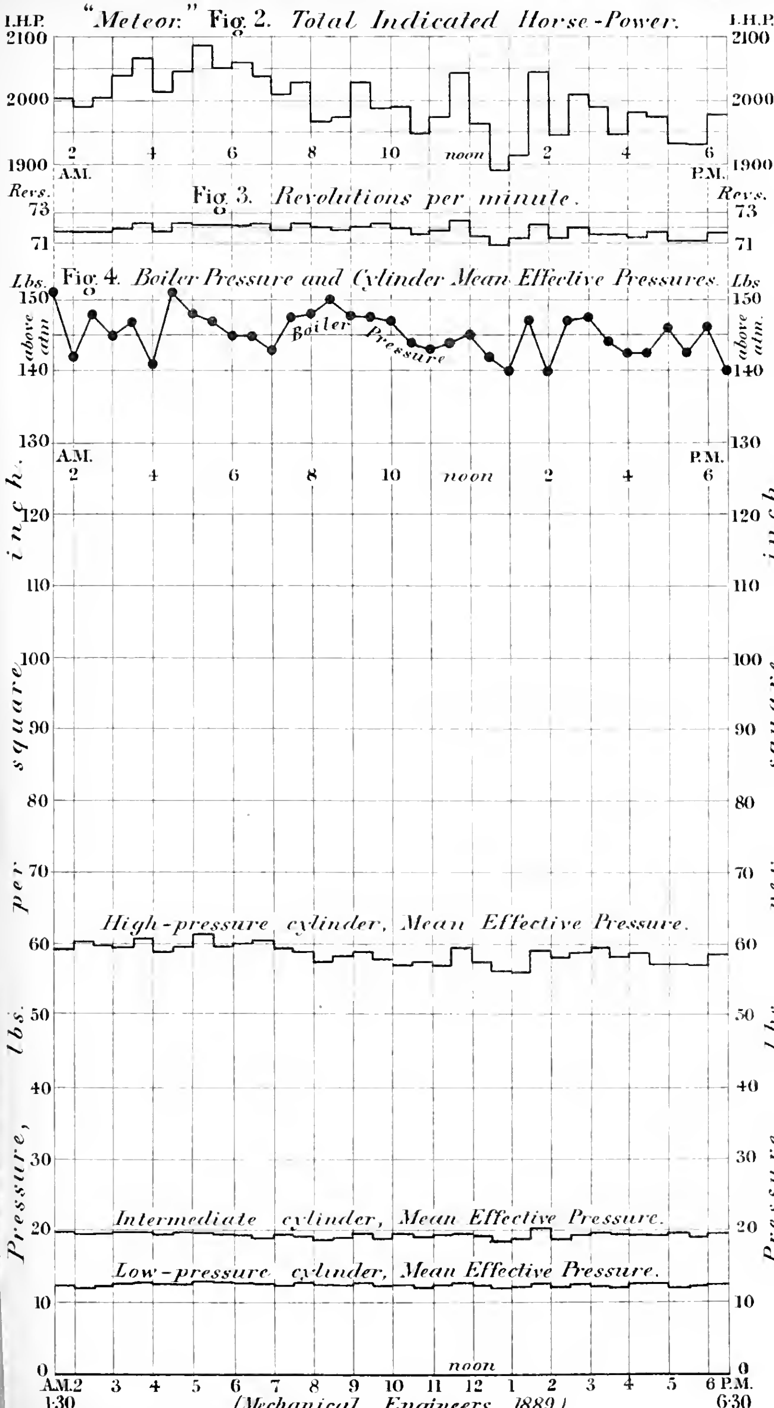
St. John and Rockwell gas condensing and carburetting apparatus; and more recently was interested in the Cooper coal-liming process. He died in London on 11th May 1889, at the age of seventy-five. He became a Member of this Institution in 1876.

Trials of the S.S. "Meteor."

Fig. 1. *Total Coal, Water, and Revolutions*



(Mechanical Engineers 1889)



(Mechanical Engineers 1889)

"Meteor" Trials, Indicator Diagrams, Set 27.

Revs. 72·0 *per min. Total I.H.P.* 2009·4.

Fig. 5. *High-pressure cylinder. I.H.P.* 666·5.

Lbs. Mean Pressures, Top end 59·8 *lbs., Bottom* 57·6 *lbs. Lbs.*

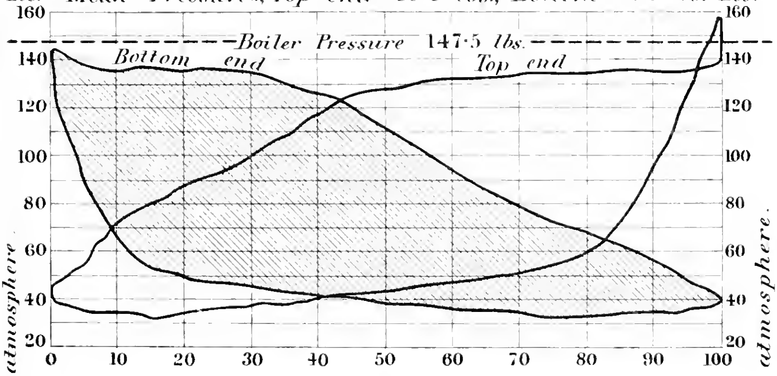


Fig. 6. *Intermediate cylinder. I.H.P.* 511·7.

Lbs. Mean Pressures, Top end 20·47 *lbs., Bottom* 18·79 *lbs. Lbs.*

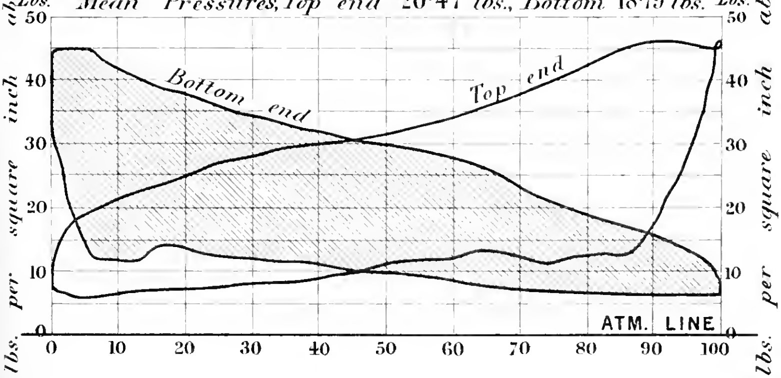
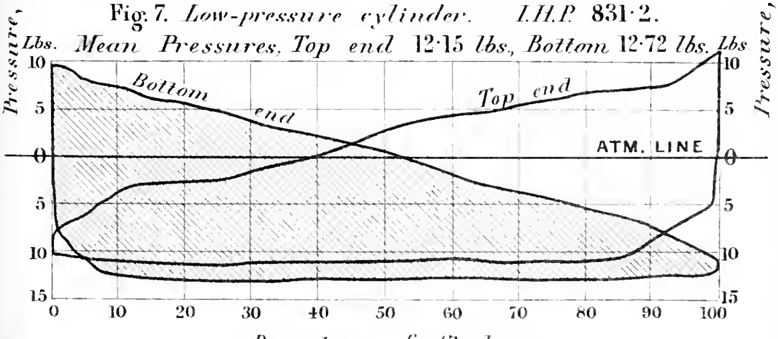


Fig. 7. *Low-pressure cylinder. I.H.P.* 831·2.

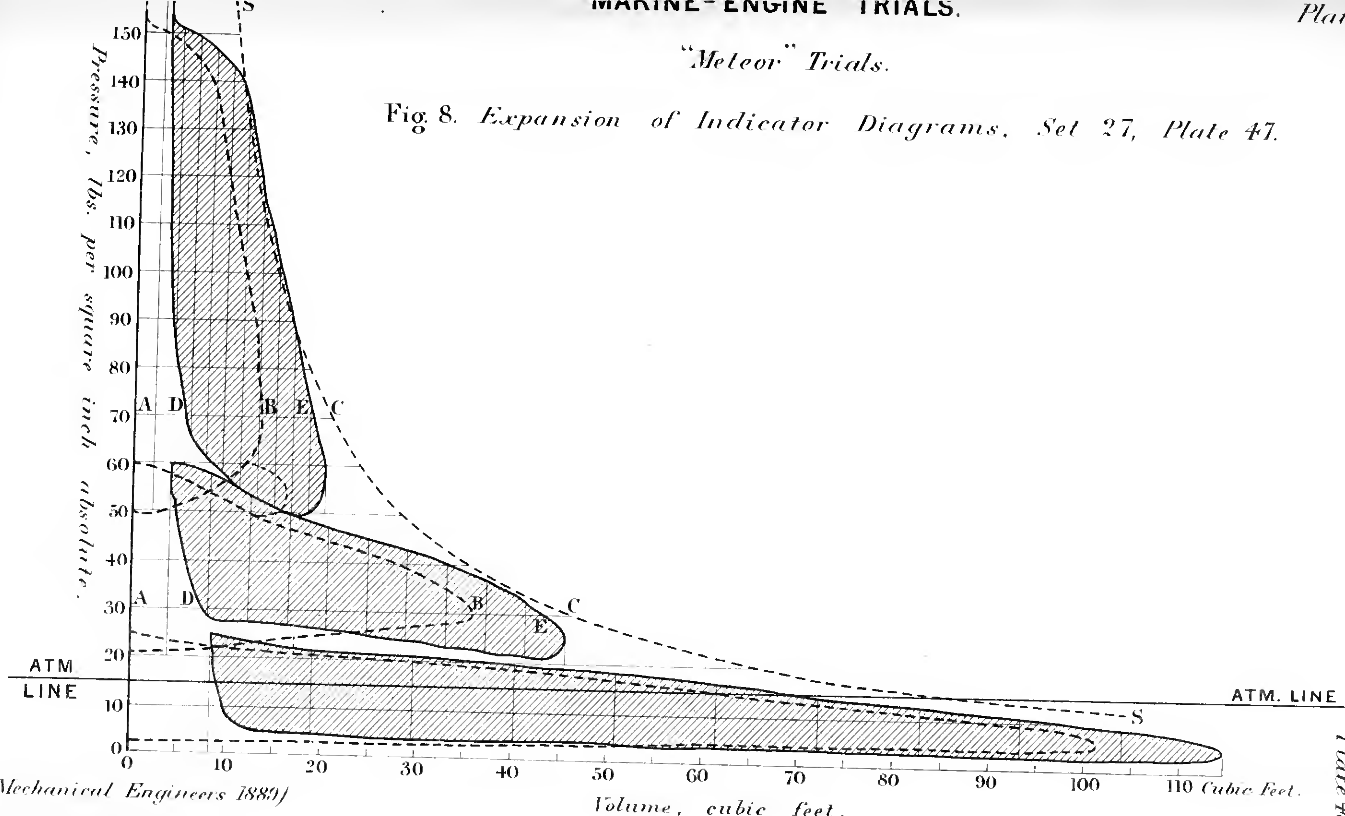
Lbs. Mean Pressures, Top end 12·15 *lbs., Bottom* 12·72 *lbs. Lbs.*



(Mechanical Engineers 1889)

"Meteor" Trials.

Fig. 8. *Expansion of Indicator Diagrams. Set 27, Plate 47.*

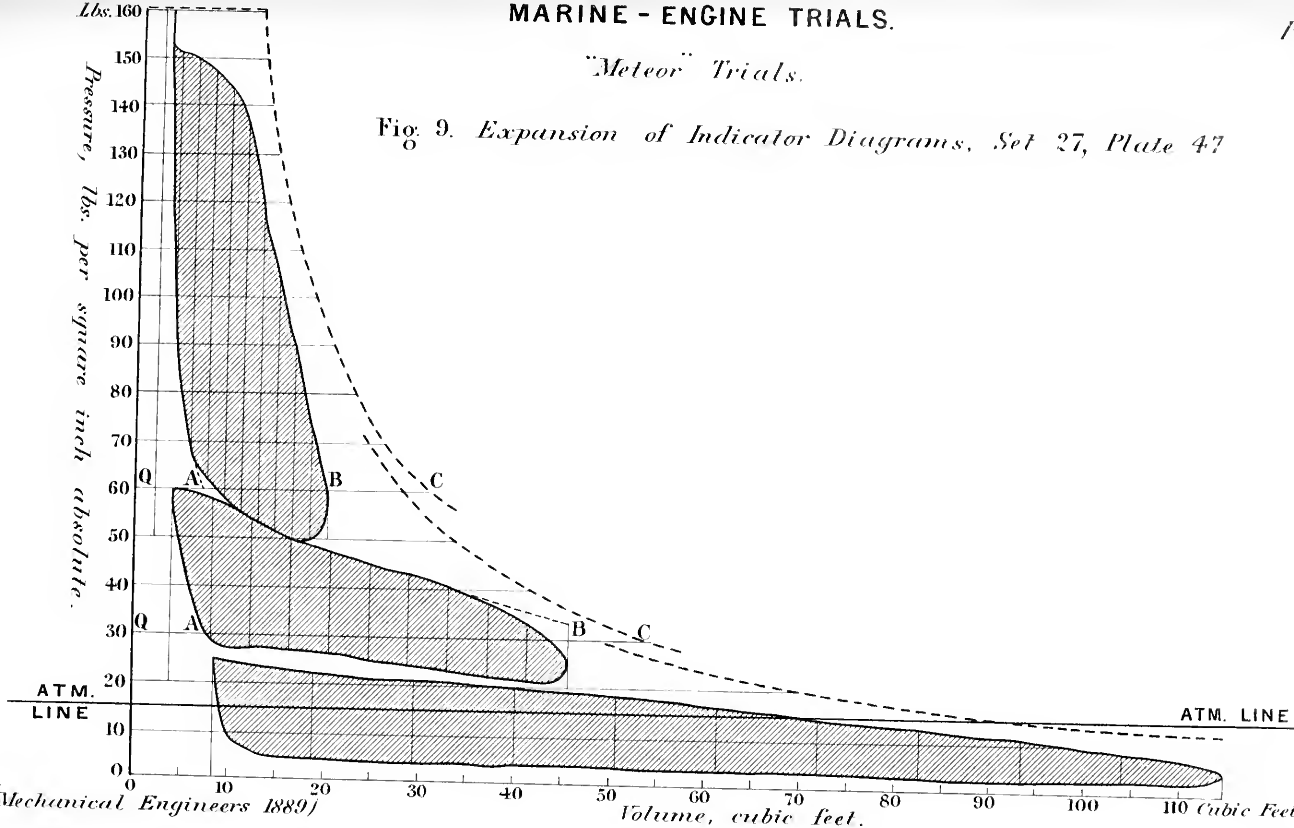


(Mechanical Engineers 1889)

MARINE - ENGINE TRIALS.

"Meteor" Trials.

Fig. 9. Expansion of Indicator Diagrams, Set 27, Plate 47



(Mechanical Engineers 1889)

"Meteor" Supplementary Trial. Table 1, Set A.

Revs. 81·0 per min. Total I.H.P. 3003.

Fig. 10. High-pressure cylinder. I.H.P. 778.

Mean Pressures, Top end 62·00 lbs., Bottom 59·80 lbs.

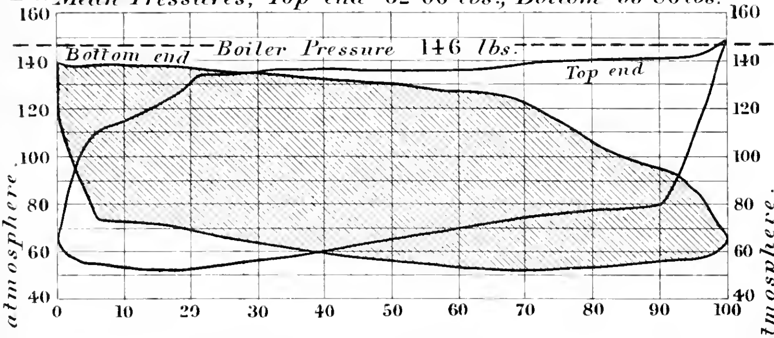


Fig. 11. Intermediate cylinder. I.H.P. 832.

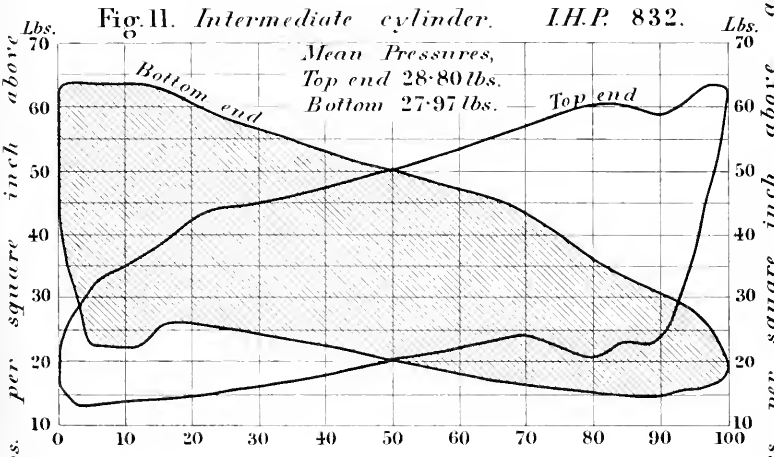
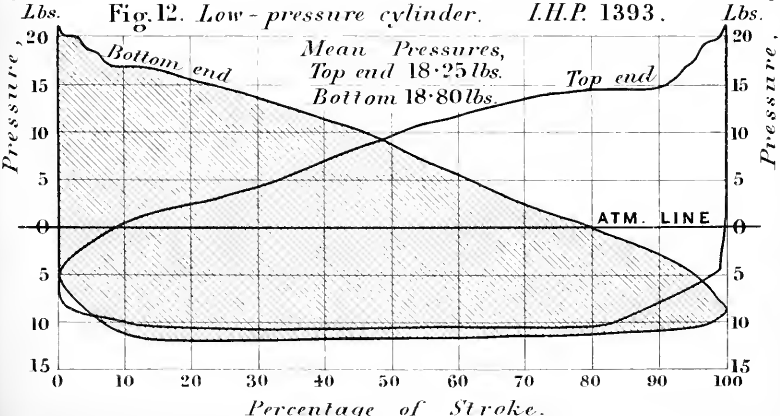


Fig. 12. Low-pressure cylinder. I.H.P. 1393.



Percentage of Stroke.

(Mechanical Engineers 1889)

"Meteor" Supplementary Trial. Table 1, Set C.

Revs. 83·1 per min. Total I.H.P. 3273.

Fig. 13. High-pressure cylinder. I.H.P. 397.

Mean Pressures, Top end 29·80 lbs, Bottom 30·70 lbs.

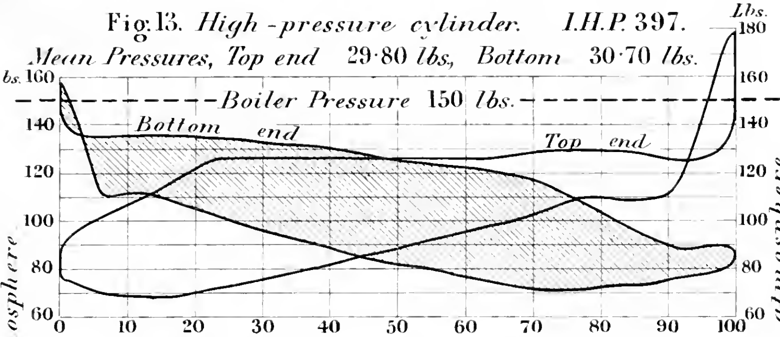


Fig. 14. Intermediate cylinder. I.H.P. 1013.

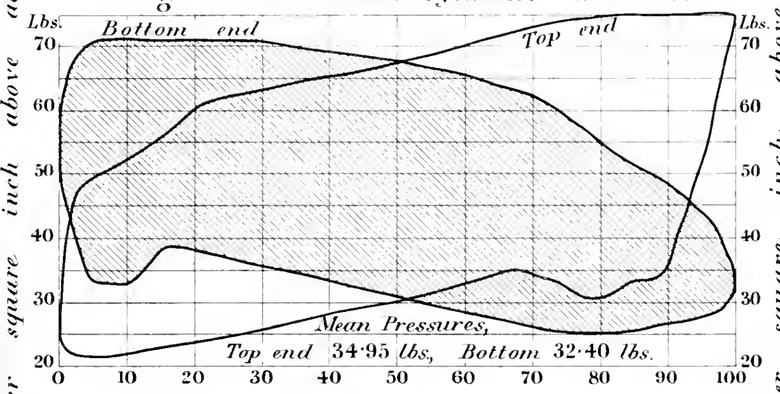
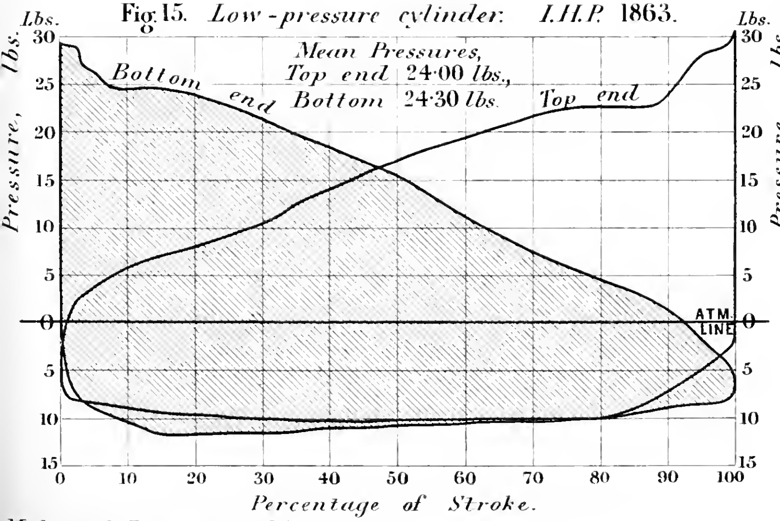


Fig. 15. Low-pressure cylinder. I.H.P. 1863.



Percentage of Stroke.

"Meteor" Supplementary Trial. Table 1, Set D.

Revs. 78·7 per min. Total I.H.P. 2745.

Fig. 16. *High-pressure cylinder. I.H.P. 796.*

Mean pressures, Top end 65·40 lbs., Bottom 62·80 lbs.

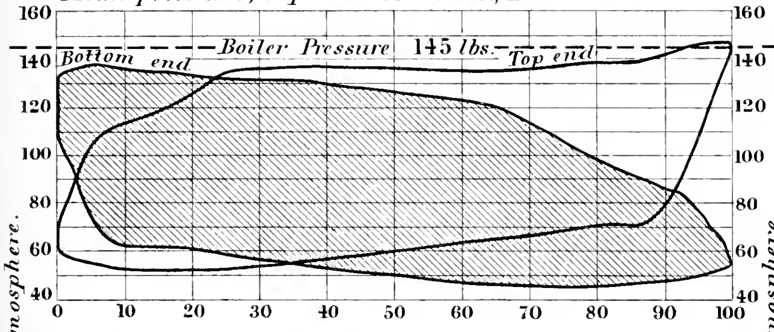


Fig. 17. *Intermediate cylinder. I.H.P. 727.*

Mean Pressures, Top end 26·10 lbs., Bottom 24·97 lbs.

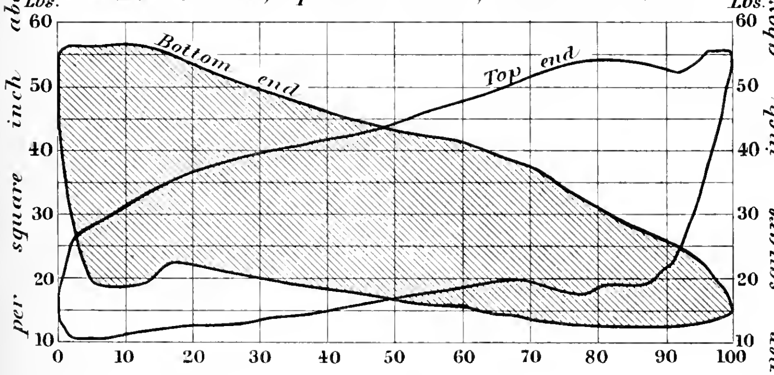
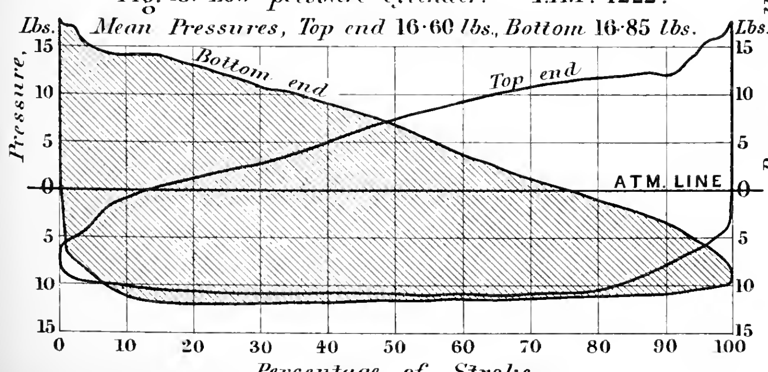


Fig. 18. *Low-pressure cylinder. I.H.P. 1222.*

Mean Pressures, Top end 16·60 lbs., Bottom 16·85 lbs.



Percentage of Stroke.

Pressure, lbs. per square inch above atmosphere.

(Mechanical Engineers 1889)

"*Meteor*" *Supplementary Trial. Table* 1, *Set* F.

Revs. 80·0 *per min.* *Total I.H.P.* 2954.

Fig. 19. *High-pressure cylinder.* *I.H.P.* 394.

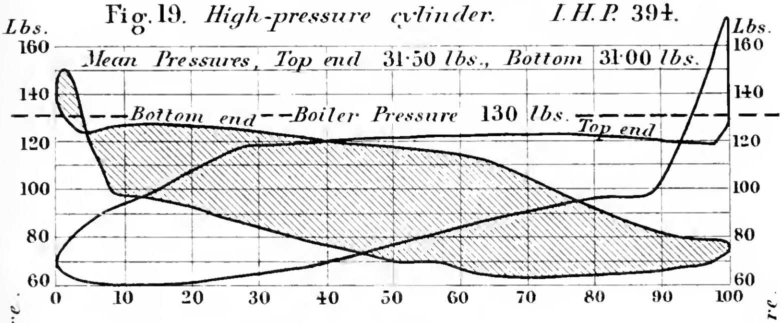


Fig. 20. *Intermediate cylinder.* *I.H.P.* 952.

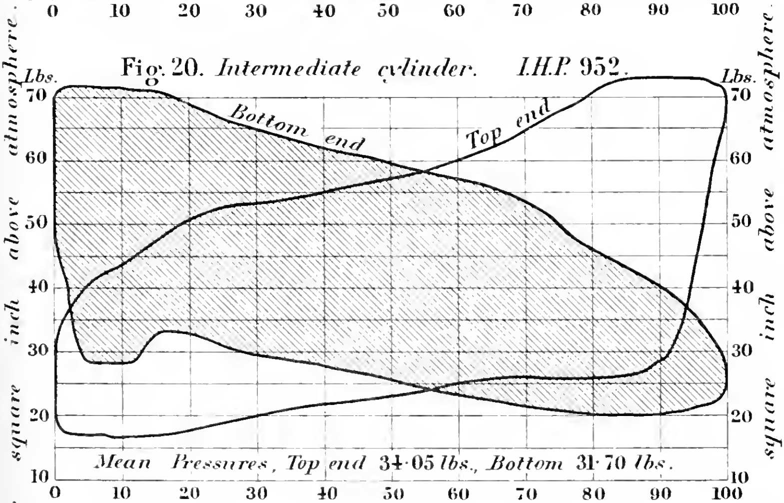
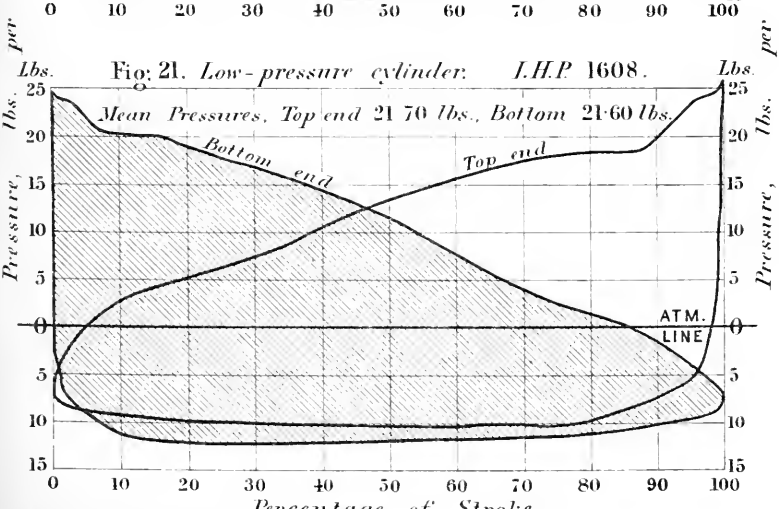


Fig. 21. *Low-pressure cylinder.* *I.H.P.* 1608.



(*Mechanical Engineers 1889*)

"Meteor" Supplementary Trial. Engines full gear astern.
Revs 76 per min. Total I.H.P. 2660.

Fig. 22. *High-pressure cylinder. I.H.P. 585.*
Mean Pressures, Top end 51·70 lbs., Bottom 45·90 lbs

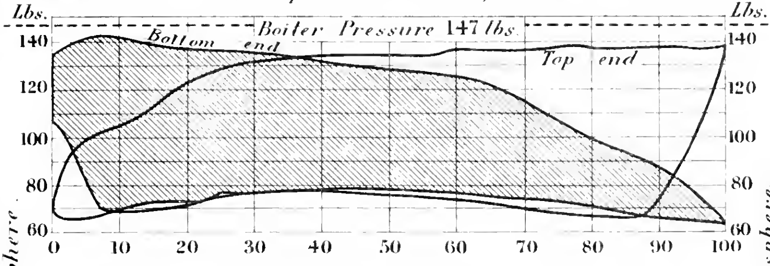


Fig. 23. *Intermediate cylinder. I.H.P. 867.*
Mean Pressures, Top end 31·40 lbs., Bottom 31·60 lbs

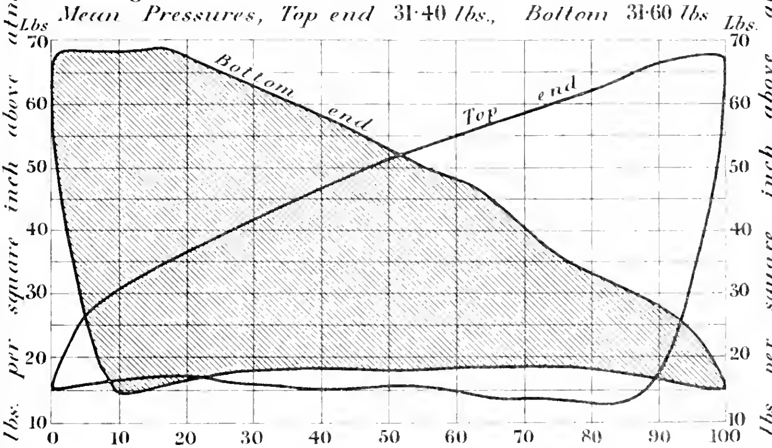
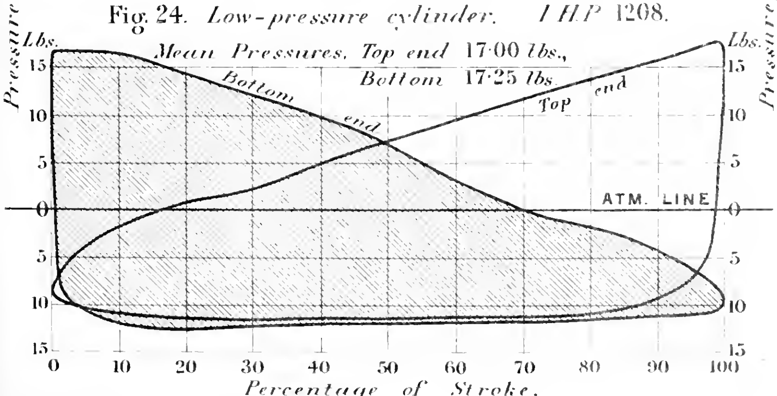


Fig. 24. *Low-pressure cylinder. I.H.P. 1208.*



(Mechanical Engineers 1889)

MARINE-ENGINE TRIALS.

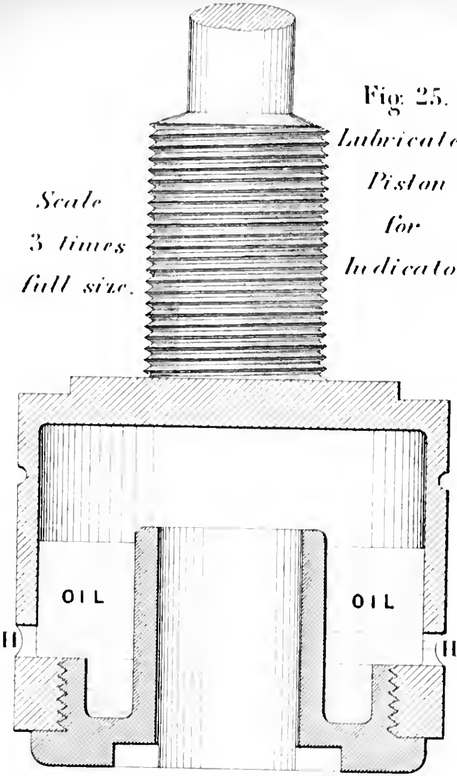
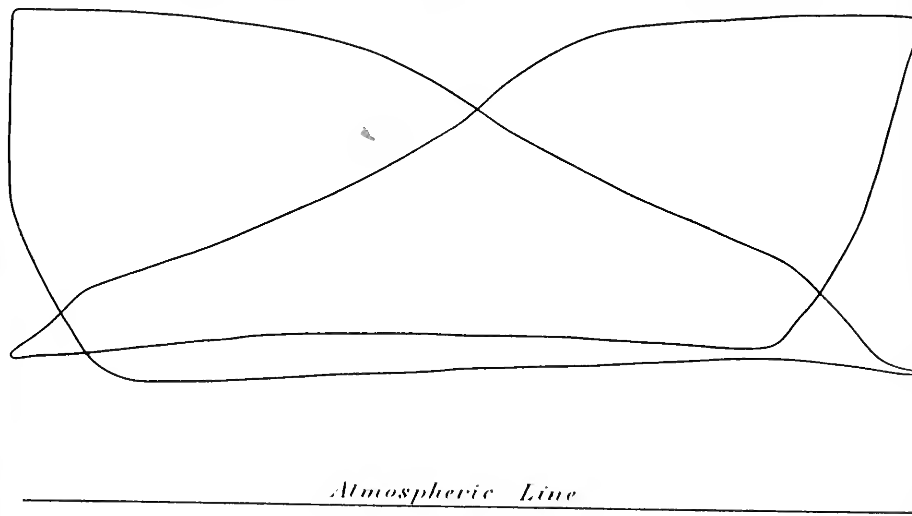


Fig. 25. Lubricated Piston for Indicator.

Scale 3 times full size.

Fig. 26. High-pressure Diagram taken with Indicator in Fig. 25 from triple-expansion engines of S.S. "Ursa."



(Mechanical Engineers 1889)

Plate 55.

DRYING IN VACUUM.

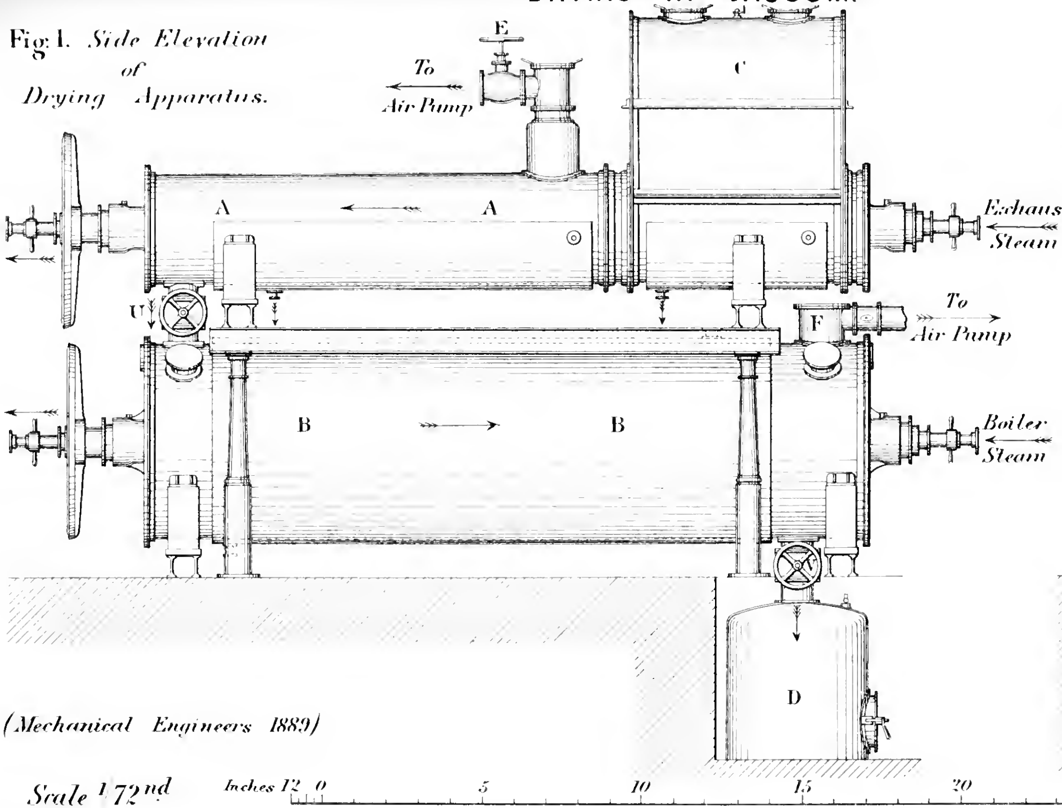
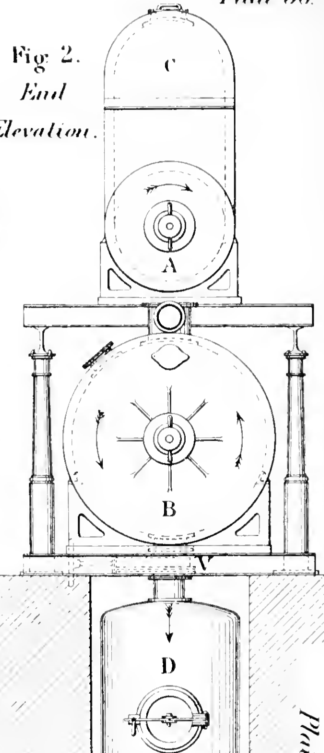


Fig. 1. *Side Elevation of Drying Apparatus.*

Fig. 2. *End Elevation.*



(Mechanical Engineers 1889)

Scale 1/72nd

Plate 56.

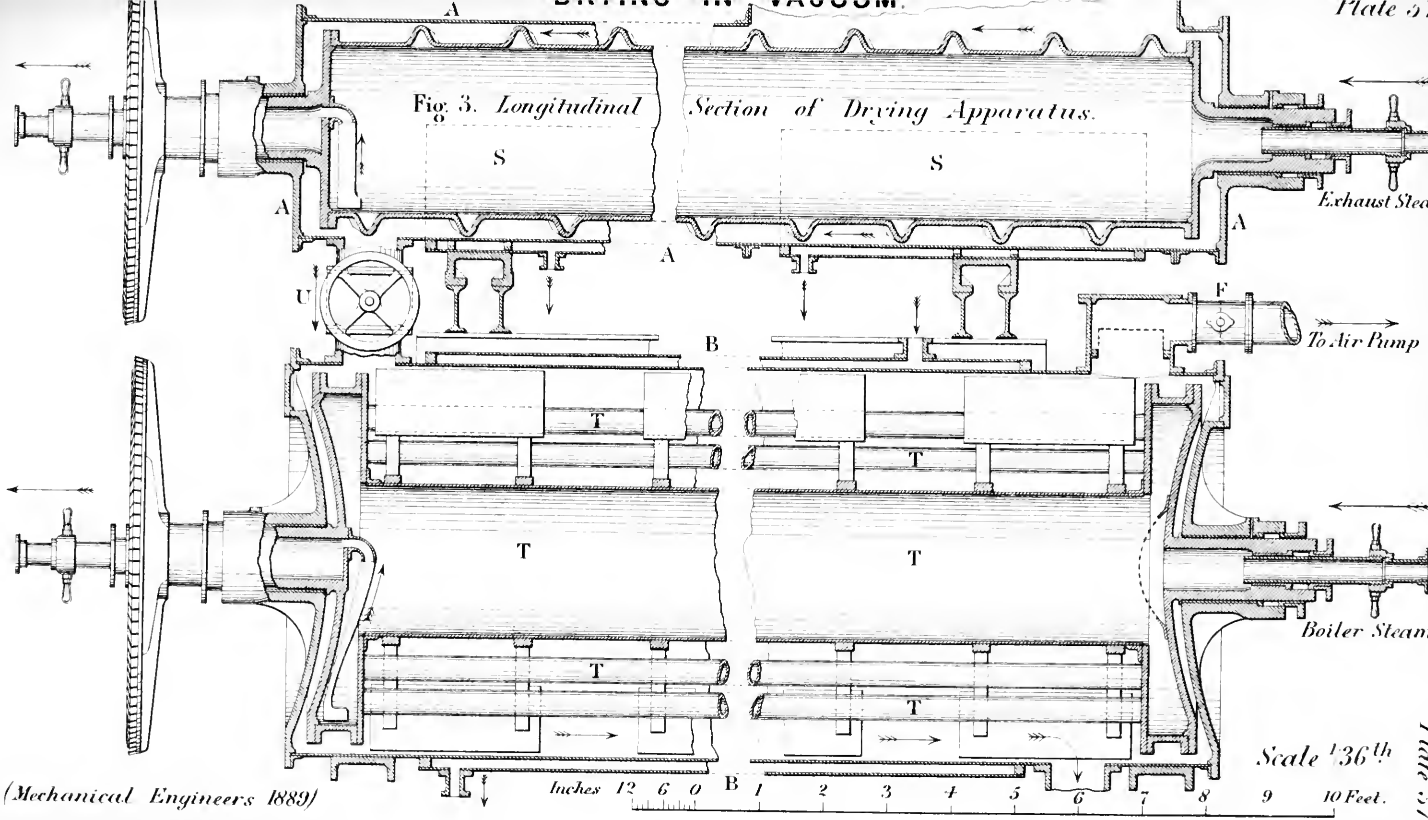


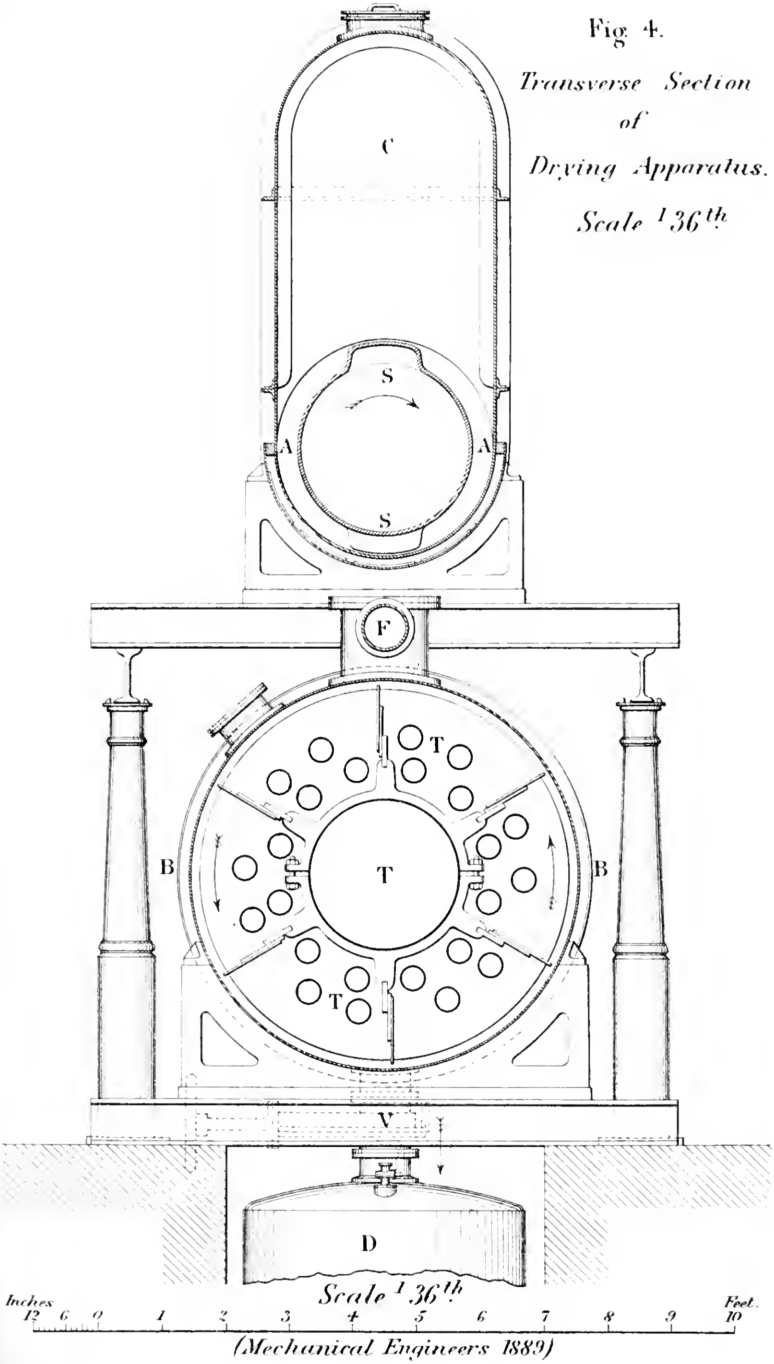
Fig. 3. Longitudinal Section of Drying Apparatus.

(Mechanical Engineers 1889)

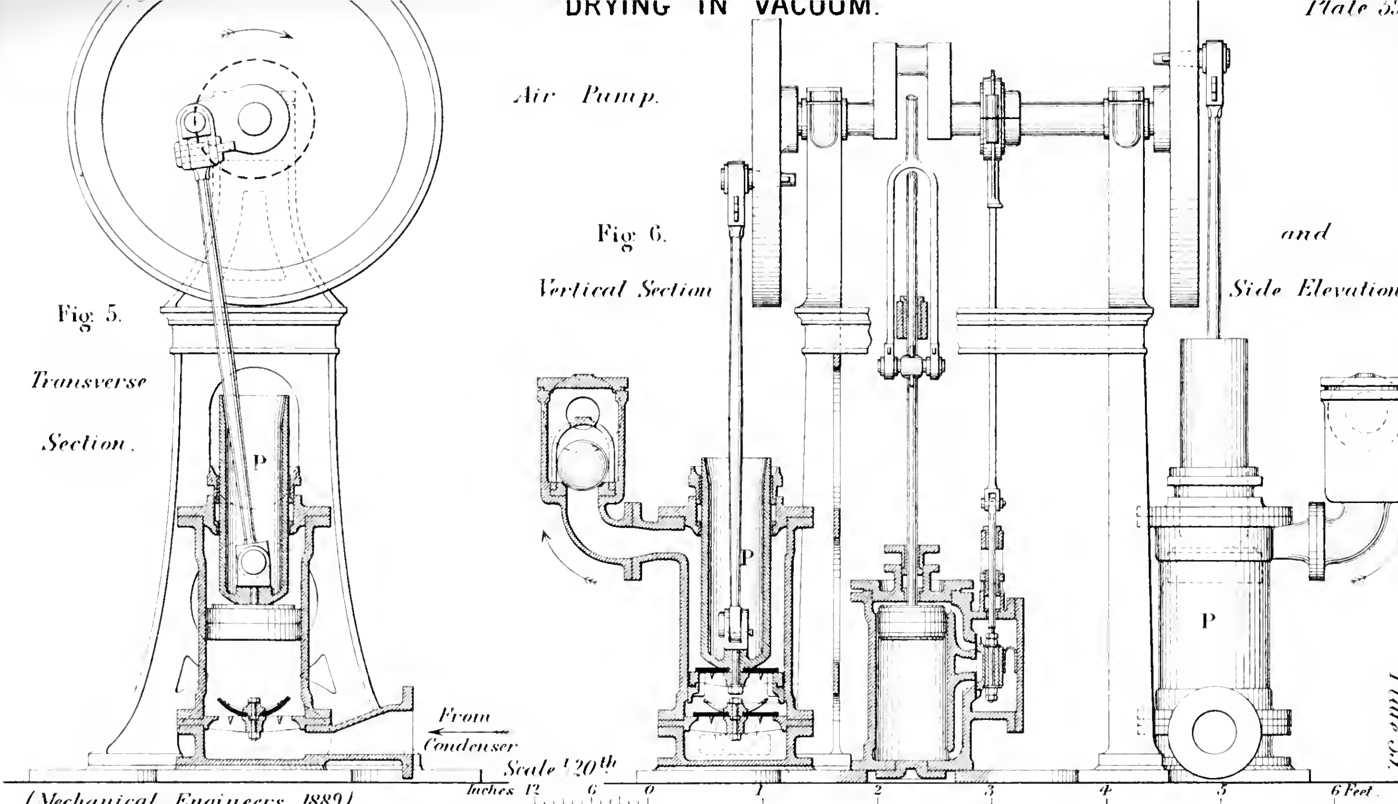
Fig. 4.

Transverse Section of Drying Apparatus.

Scale 1/36th.



(Mechanical Engineers 1889)


Air Pump.
Fig. 5.
Transverse Section.
Fig. 6.
Vertical Section
and
Side Elevation.
P
P
P
From Condenser
Scale 1/20th
Inches 12 6 0 1 2 3 4 5 6 Feet.
Plate 59.

Air-Pump and Jet Condenser.

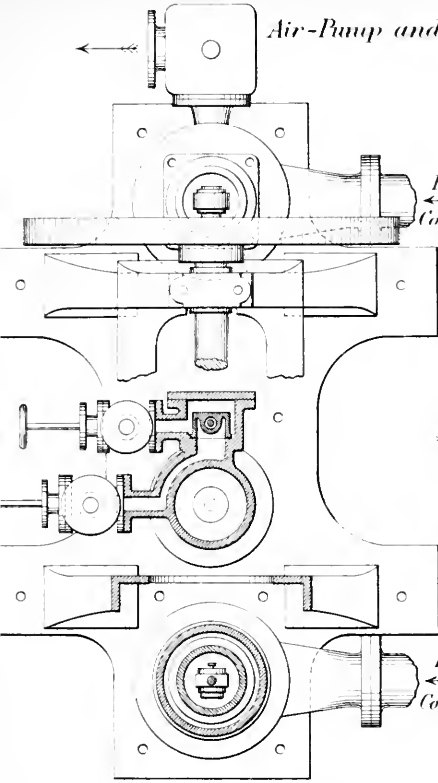


Fig: 7. Plan of Air-Pump.
Scale 1/20th

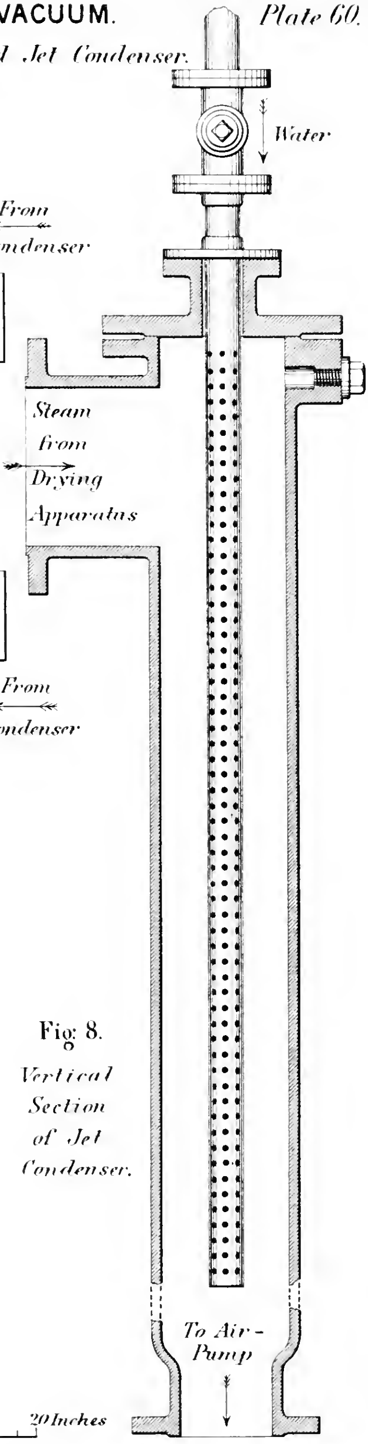


Fig: 8.
Vertical
Section
of Jet
Condenser.

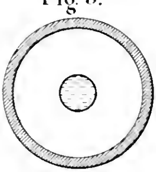


Fig: 9.
Transverse
Section
of Jet
Condenser.

Scale 1/10th

Scale 1/10th

0 5 10 15 20 Inches

Institution of Mechanical Engineers.

PROCEEDINGS.

July 1889.

The Summer Meeting of the Institution was held in Paris, commencing on Tuesday, 2nd July 1889, at Half-past Nine o'clock a.m.; Charles Cochrane, Esq., President, in the chair.

The President and Council and Members were received in the large Lecture Theatre of the Conservatoire des Arts et Métiers, by M. Gustave Eiffel, President of the Société des Ingénieurs Civils, and by other members of the Reception Committee of the Society.

M. Eiffel addressed the President and Members as follows:—Gentlemen, in the name of the Société des Ingénieurs Civils de France, represented here by their Council and by many of their most eminent Members who gladly join me on this occasion, I have very great pleasure in offering a most cordial welcome to the Institution of Mechanical Engineers at the opening of their present meeting in Paris. I beg to assure them that the Members of our Society are happy to receive them as colleagues whom we are proud to recognise as having done the greatest honour all over the world to our grand profession of engineering.

Colonel Laussedat, the distinguished Director of the Conservatoire des Arts et Métiers, fully intended to be present today, and has desired me to express his regret that he is prevented from receiving you himself in this renowned establishment over which he presides. He is detained at the Exhibition by imperative duties, and is obliged to ask you to excuse him for not being with you.

English engineers can hardly be ignorant of the high estimation in which they are held by their French brethren, who have all learnt,

(M. Eiffel.)
not only during their professional training, but even from their earliest childhood, thanks to the voice of public opinion, that England occupies the foremost place in mechanical engineering, which is specially represented at this meeting. To her are due, as is well known, not only the railway and the locomotive, but also many other important inventions which have largely contributed to general progress, and have thus conferred upon the world benefits calling for the gratitude of mankind. We are further indebted to you for the structures you have originated in iron and steel, as represented by that admirable work, the Britannia Bridge, which was the wonder of its time, and has now been succeeded by another triumph in the Forth Bridge; and many are the illustrious names which intervene between that of Robert Stephenson and that of Benjamin Baker. While in all these great railway and other works I have no hesitation in recognizing you as our precursors, we too have brought to bear in the same direction our national engineering abilities, particularly our love of clearness and of mathematical reasoning, which will not have failed to influence the progress of all the applied sciences.

We are particularly glad to welcome you in France on the occasion of our great Exhibition, whereby we hope above all to testify our hearty desire to create a fresh bond of union between the engineers of our two nations. We cordially wish to witness a strengthening of that mutual understanding, of which the importance is daily becoming more conspicuous, inasmuch as engineers of all countries alike are soldiers fighting under a common banner for the progress of mankind.

I therefore bid you all a hearty welcome, and trust that your present Meeting will mark a fresh step forwards in that march of scientific progress to which are devoted the lives of Engineers.

The PRESIDENT was sure the note of welcome given by M. Eiffel could be mistaken by no one who heard it. In his reference to the engineering triumphs of Great Britain he had been so modest as to take no notice whatever of the great triumphs by which France had been distinguished, and to which he had lent his own powerful

aid in a manner well known not only in France but in all countries throughout Europe. If M. Eiffel could speak in praise of English engineers, the latter could also find a great deal worthy of praise in France, culminating in the two mammoth works with which M. Eiffel was himself associated, namely the Garabit Viaduct and the Eiffel Tower; and certainly his own name would rank with those of Robert Stephenson and Benjamin Baker, to whom he had made such pleasing reference. M. Eiffel had expressed his pleasure in welcoming the Members of the Institution; and he was quite sure that the Members in their turn would join with one accord in expressing their gratification at receiving so cordial a welcome from their brother engineers in the city of Paris; and they would most certainly concur in the idea expressed by him as to their being all alike engaged in working on behalf of the progress of humanity. The Members would not forget how greatly they were indebted to Colonel Laussedat for his kind permission to meet in the hall in which they were now assembled; and while they all regretted his unavoidable absence, they had heard from M. Eiffel the cause to which it was owing. Nor would they overlook the fact that they had amongst their visitors on this occasion so distinguished an engineer as M. Ferdinand de Lesseps, upon the merits of whose great works it would be superfluous to enter; it was enough to know that their meeting was honoured by the presence of so eminent an engineer. Possibly many Englishmen had flattered themselves that their countrymen were the sole inventors of the steam engine; but he observed that there was in this building a monument erected to the memory of Denis Papin, for whom it was claimed that he was the inventor of the steam engine in 1690: thus showing how discoveries might take place in two countries quite independently of each other. The monument had been erected by national subscription only two or three years ago; and it was highly gratifying to observe how the same ideas were similarly developed in different countries.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following thirty-seven candidates were found to be duly elected:—

MEMBERS.

GEORGE ADDY,	Sheffield.
CHARLES FREDERICK ARCHER,	London.
WILLIAM JAMES BAYFORD,	Delhi.
PHILIP BRIGHT,	London.
WILLIAM CALLAN,	London.
ROBERT COEY,	Dublin.
JOHN FREELAND FERGUS COMMON,	Cardiff.
WILLIAM HART CULLEN,	Oldbury.
ERNEST HOWARD FOSTER,	Paris.
EBENEZER HALL-BROWN,	Hartlepool.
JOHN HOPWOOD,	Mendoza.
COOPER HORSFIELD,	Leeds.
RICHARD HOSKEN,	Chepstow.
JOHN HUGHES,	Chester.
WILLIAM CHARLES IRVINE,	West Hartlepool.
CHARLES WILLIAM JAMES,	Paris.
RALPH KANTHACK,	Jena.
ALEXANDER MACLAY,	Glasgow.
The Hon. JAMES MARTIN,	Gawler.
JOHN HENRY A. MCINTYRE,	Glasgow.
BERNARD ADOLPH MÜNSTER,	Yokosuka.
THOMAS OWEN,	Derby.
DAVID CODRINGTON SELMAN,	Bristol.
ISAAC SHONE,	London.
DAVID SOUTER-ROBERTSON,	Saharanpore.
WILLIAM PENROSE TRENERRY,	Florence.
THOMAS WARSOP,	Coniston.
JOHN RICHARDSON WIGHAM,	Dublin.

ASSOCIATES.

CARL JOHANN WILHELM GÖTZ,	Manchester.
GEORGE FRANCIS GREGORY,	London.

William Henry Miles, . . .	Bournemouth.
Joseph Nasmith, ...	Manchester.

GRADUATES.

Walter Bernard Challen, . .	Birmingham.
George Norcliffe Cook, . . .	Sheffield.
Lucien Alphonse Legros, . . .	London.
Edgar Lyon Paget, ...	Loughborough.
John Cuthbert Wigham, . . .	Dublin.

The following Paper was then read and discussed:—

Description of the Lifts in the Eiffel Tower; by Mr. A. Ansaloni, of Paris.

At the conclusion of the reading of the Paper the Results of the Working of the Lifts to date were communicated verbally by M. Eiffel, President of the Société des Ingénieurs Civils.

The following Paper was read and partly discussed:—

The Rationalization of Regnault's Experiments on Steam; by Mr. J. Macfarlane Gray, of London.

At a Quarter past Twelve the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the large Lecture Theatre of the Conservatoire des Arts et Métiers, Paris, on Wednesday, 3rd July 1889, at Half-past Nine o'clock a.m.; Charles Cochrane, Esq., President, in the chair.

The following Papers were read and discussed:—

On Warp Weaving and Knitting, without Weft; by Mr. Arthur Paget, of Loughborough, Vice-President.

On Gas Engines, with description of the Simplex Engine; by Mr. Edouard Delamare-Deboutteville, of Rouen.

Shortly after Noon the Discussion was adjourned to the following morning.

The ADJOURNED MEETING was held in the large Lecture Theatre of the Conservatoire des Arts et Métiers, Paris, on Thursday, 4th July 1889, at Half-past Nine o'clock a.m.; CHARLES COCHRANE, Esq., President, in the chair.

The Discussion on Mr. Gray's Paper on the Rationalization of Regnault's Experiments on Steam was resumed and completed; as was also that on Mr. Delamare-Deboutteville's Paper on Gas Engines. The two remaining Papers announced for reading and discussion were adjourned to subsequent meetings.

The PRESIDENT proposed the following Votes of Thanks, which were passed by acclamation :—

To the Director of the Conservatoire des Arts et Métiers, Colonel Laussedat, for the facilities and accommodation he has so obligingly afforded for again holding the Meeting of this Institution in the Conservatoire; and to the Engineer, M. Masson, for his kindness in carrying out the necessary arrangements.

To the President and Members of the Société des Ingénieurs Civils, and particularly to their Reception Committee, and their Agent General, M. Armand de Dax, for the highly acceptable and hospitable arrangements they have made for welcoming and entertaining the Members of the Institution during their visit to Paris.

To the Proprietors and Authorities of the various Engineering and Manufacturing Works and other Establishments so liberally opened to the visit of the Members on the occasion of this Meeting; and to the Railway Authorities for the special facilities so obligingly afforded in connection therewith.

To the Honorary Local Secretary, Mr. Henry Chapman, for his renewed kindness in again affording to the Institution the benefit of his valued aid and experience in ensuring the success of this third Meeting of the Institution in Paris; and to his Manager, M. Henri Vaslin, for the energetic manner in which he has shared in carrying out the details of the various arrangements.

Mr. Arthur Paget, Vice-President, was sure that all present would desire to pass a most hearty vote of thanks to the President. This was the third occasion on which he had himself visited Paris for a meeting of the Institution, and he had never known a president throw his heart and soul more thoroughly into his work than Mr. Cochrane had done, or perform it more to the satisfaction of all the Members. He therefore proposed that an earnest vote of thanks be passed to the President for his valuable labours.

The motion was carried by acclamation.

The Meeting then terminated shortly after Noon. The attendance was 189 Members and 79 Visitors.

DESCRIPTION OF THE LIFTS IN THE EIFFEL TOWER.

By Mr. A. ANSALONI, of Paris.

The Eiffel Tower, Fig. 1, Plate 61, though 984 feet high, would be of comparatively little interest if seen only at a distance. The details of this gigantic structure call for close examination; and from its successive platforms, as they rise one above another, a widening prospect is enjoyed, which at the summit extends to a distance of forty or fifty miles round.

In the erection of this work, the designer has also had in view the means of rendering it accessible to the greatest number. To climb 1,800 steps on foot to the summit was not to be thought of, though a staircase may suffice for mounting to the first platform, 189 feet above the ground. This platform can accordingly be reached without fatigue by two wide staircases, constructed in the east and west piers. Even the second platform may also be reached by small winding staircases which occupy the four corners of the tower.

Independently of the staircases however, the ascent is made by means of Lifts arranged in the following manner. Two lifts on the Roux, Combaluzier, and Lepape system, with chains of jointed rods, lift from the ground to the first platform, working alongside the staircases in the east and west piers. Two American lifts on the Otis plan work in the north and south piers, starting likewise from the ground and rising to the second platform at 380 feet height, with option of stopping at the first platform. Lastly, by a lift on the Edoux system, placed vertically in the centre of the tower, visitors are raised from the second platform to the third at a height of 906 feet above the ground.

Each Roux lift is capable of raising 100 persons at a speed of 197 feet per minute, and will make twelve trips per hour; the two

lifts together will thus raise 2,400 persons per hour to the first platform, where there are restaurants, cafés, and large covered galleries, whence to enjoy the surrounding views. The two Otis lifts will each hold 50 persons, and work at a speed of 394 feet per minute, and make eight trips an hour, thus conveying 800 persons per hour to the second platform. The Edoux lift will hold from 60 to 70 persons, and make twelve trips per hour, assuming a speed of 177 feet per minute; it will thus raise to the third platform the 800 persons per hour brought up by the American lifts.

Roux, Combaluzier, and Lepape Lifts. (Plates 62–66.)

These lifts consist essentially of a double chain of jointed rods JJ, Figs. 2 to 4, Plate 62, fitted at each joint with a small pair of wheels, on which the chains run in guide-trunks TT fastened to the inclined girders G that carry the rails R whereon the cabin runs. The rods are $1\frac{3}{4}$ inches diameter and 3·28 feet long; and jointed together they form a complete circuit, each chain passing at top over a pulley $11\frac{1}{2}$ feet diameter, placed above the first platform. On each side of the cabin is bolted a wrought-iron bar, which forms one link in the chain of jointed rods; and in order to let this attachment pass, each of the two lower guide-trunks has a longitudinal slot S, Fig. 4, all along its inner side facing the cabin; the upper trunk, containing the return half of the chain, is entirely closed. At the bottom, each chain of rods passes under a driving wheel W, Plate 63, $12\frac{3}{4}$ feet diameter, with twelve arms; on the extremity of each arm is a hollowed steel tooth, by which the eyes of the rods are caught successively, and thus the chain of rods is driven. The driving wheel of each circuit is driven from a hydraulic plunger, $41\frac{1}{3}$ inches diameter and $16\frac{1}{2}$ feet stroke, which works horizontally in a hydraulic cylinder 47 inches diameter, Plates 63 and 64. A pair of 63-inch pulleys carried on the plunger head H engage a pair of triple-link pitch-chains N, one end of which is fixed to the cylinder bed-plate, whilst the other end takes half a turn round a double drum D $23\frac{1}{2}$ inches diameter, which is keyed on the shaft of the driving

wheel W. For each lift the mechanism is in duplicate; but the driving shafts are coupled together, and the motion is regulated by two water-valves VV, Plate 66, worked simultaneously, by which water is admitted from the reservoirs situated on the second platform, at a height of 380 feet, for raising the lift; while in the descent the water is allowed to exhaust gradually from the cylinders. The water pressure accordingly acts in the ascent only; the descent is made by the weight of the cabin, which is more than sufficient for the purpose, and is partly counterbalanced by lead counterweights placed on some of the rods in the upper or closed guide-trunks.

Balance.—The weight of the two-storey cabin empty is about 14,080 lbs.; the counterweights weigh 6,600 lbs., leaving an unbalanced load of 7,480 lbs., of which the component parallel to the track inclined at 54° 35′ is $7{,}480 \times \sin 54° \, 35' = 7{,}480 \times 0 \cdot 815 = 6{,}096$ lbs. This load is sufficient to overcome frictional resistance, as well as to drive the plungers home to the end of the cylinders, and thus enables the cabin to descend empty.

In ascending with 100 persons, estimated at 15,400 lbs., the unbalanced weight of the cabin being 7,480 lbs., there is a total load of 22,880 lbs., representing on the incline a pull of $22{,}880 \times 0 \cdot 815 = 18{,}647$ lbs. at the extremity of the arms of the driving wheels. On the plungers, according to the ratio of the tackle and without allowing for friction, this pull becomes $18{,}647 \times \frac{12 \cdot 75 \times 12}{23 \cdot 5} \times 2 = 18{,}647 \times 13 = 242{,}411$ lbs. Assuming from 45 to 50 feet loss of head in the pipe from the reservoirs on the second platform to the cylinders, there will still remain a pressure of 142 lbs. per square inch on the plungers, or $2 \times 1{,}342$ sq. ins. $\times 142 = 381{,}798$ lbs. Of the difference, $381{,}798 - 242{,}411 = 139{,}387$ lbs., about one half will be absorbed in overcoming the various frictional resistances of the lift.

Cabins.—The cabins, Fig. 8, Plate 65, consist of two separate rooms, one above the other, each $8\frac{1}{4}$ feet high and $10\frac{1}{2}$ feet wide and $13\frac{3}{4}$ feet long. Each room rests on a wrought-iron floor-frame. By means of slanting cheeks the travelling chains of jointed rods are

fastened not only to the sides of the lower room but also to each of the two floor-frames.

Each cabin is carried on four wheels, two on each side, which run on the inclined track. The two rooms are fitted with sliding doors at the sides, which are opened and closed from the outside by the conductor of the lift, who stands on a platform projecting in front of the lower room; or an attendant stationed on the landings minds the doors of the upper room. Each room is fitted with a bench at the back for the whole width, and several short seats; the total accommodation provided is for 100 persons, 30 sitting and 70 standing.

Water Distribution.—The water from the reservoirs on the second platform is brought to the foot of each pier through a wrought-iron pipe about 10 inches diameter. The exhaust water which has passed through the cylinders is returned through another 10-inch pipe to a feed tank which supplies the pumps placed in the south pier, Fig. 47, Plate 77.

The water distributors VV for the two cylinders are placed between the supply and exhaust pipes, Figs. 6 and 7, Plates 64 and 65. Each distributor consists of a cast-iron box with three compartments, Fig. 9, Plate 66, which are separated by two gun-metal valves partially balanced. The valve spindles are worked by two cams M mounted opposite each other on the same shaft, so as to act on one valve or the other according as the shaft is turned one way or the other. The cam shaft is controlled by means of a double rope running along the route of the cabin, so that the conductor can work it at any height for regulating the speed. The cabins are stopped automatically on arriving at either end of the trip by means of tappets A, Plates 63 and 64, which are struck by the heads of the plungers at the extremities of their stroke.

Safety.—Should the chain break at any part, the cabin would simply stop. It could not fall, because the rods forming the chains are constantly abutting against one another; and as the chains are confined in the closed guide-trunks, they cannot buckle under compression. Moreover the mechanism is double, one set on each

side of the cabin; and each set is capable of sustaining the whole weight of the cabin, if not of raising it.

Otis Lifts. (Plates 67–75.)

The Otis lift is like a tackle acting inversely, the power being applied direct to the movable pulley-block, while the free end of the rope is attached to the load. The power is derived from a hydraulic cylinder H, Fig. 12, Plate 67, 38 inches diameter and 36 feet long, having a piston with two $4\frac{1}{4}$ inch rods, the upper ends of which are fastened to a truck Y carrying six grooved pulleys of 5 feet diameter. The hydraulic cylinder is shown in section in Fig. 14, Plate 68, the piston with two rods in Figs. 17 and 18, and the travelling pulley-truck in Plate 72. The cylinder is supported on two girders about 131 feet long, inclined at an angle of $61^\circ\ 20'$, as shown in Plates 67 and 68. These girders carry also the path on which the pulley-truck runs; and at their upper end are mounted six stationary pulleys, corresponding with the movable pulleys Y, the whole thus forming a gigantic twelve-purchase tackle. The rope is quadrupled, being composed of four steel-wire ropes of 0·79 inch diameter; the dead end is fastened to the top of the girders by means of a whipple-tree, so as to secure equal tension on each of the four component ropes. The free end of the rope rises above the second platform, being guided by flanged pulleys; the four ropes are then divided into two pairs, which pass down each side of the lift-track and are attached to the safety apparatus beneath the cabin, Fig. 29, Plate 73. In order to diminish the stress on the piston, amounting theoretically to twelve times the load to be lifted, the dead weight is partly balanced by a counterweight T, Fig. 12, leaving only enough unbalanced for enabling the cabin to descend of itself when empty, and to raise thereby the pulley-truck and the piston; the water pressure is admitted into the top only of the hydraulic cylinder, which is thus single-acting. The counterweight consists of a truck 27 feet long, on four wheels, which is loaded with cast-iron weights; it travels upon a track 148 feet long, laid on girders situated directly beneath the lift-track, near the base of the

tower, in a straight portion inclined at 54° 35′, Plate 67. It is connected to the cabin by two steel-wire ropes of 0·9 inch diameter, arranged as a three-purchase tackle, and passing over sheaves above the second platform, whence they descend at each side of the lift-track, parallel to the main ropes, and are similarly attached to the safety gear beneath the cabin, Fig. 29.

Balance.—The cabin and its truck, with safety appliances and other gear, make up a weight of 23,900 lbs., which when resolved parallel to the 54° 35′ inclination of the lift-track is reduced to 23,900 × 0·815 = 19,510 lbs. The counterweight of 55,000 lbs. becomes at the same inclination equivalent to 55,000 × 0·815 = 44,970 lbs., capable of balancing 14,660 lbs. on the cabin, after allowing for friction. There remains therefore an unbalanced weight of 19,510 − 14,660 = 4,850 lbs., to which must be added the resultant weight of fifty passengers, say 7,700 lbs. × 0·815 = 6,280 lbs.; and also the dead resistances, together with the increase of load due to the steeper inclination of 78° 9′ in the upper part of the track, say 4,740 lbs. The total resistance is accordingly 4,850 + 6,280 + 4,740 = 15,870 lbs.

The stress on the piston rods will theoretically be twelve times this amount, or 15,870 × 12 = 190,440 lbs. But the weight of the pulley-truck and also that of the piston have to be deducted, representing together about 33,060 lbs. in favour of the power. The height of fall from the level of the reservoirs at the second platform down to the discharge of the water from the cylinder is $393\frac{1}{2}$ feet; allowing for loss of head, and deducting the area of the two piston-rods, a pressure of 156 lbs. per square inch may be taken in the cylinder of 1,134 − 28 = 1,106 square inches net area; and 1,106 × 156 = 172,530 lbs. The total power is therefore 33,060 + 172,530 = 205,590 lbs., which is considerably greater than the power required to balance the total resistance of 190,440 − 33,060 = 157,380 lbs. on the piston.

Cabins.—The cabins, Fig. 11, Plate 67, are nearly identical in dimensions with those of the Roux lifts; and that the two rooms

accommodate only 50 persons instead of 100 is in consequence of seats being provided for all the passengers, as a precaution against the tilting movement of the cabin during the journey, owing to the change of inclination of the track, which is 23° 34′ steeper between the first and second platforms. The consequence is that, if the floor of the cabin were horizontal during the lower part of the trip, it would assume a slope of $43\frac{1}{2}$ in 100 during the upper part. To obviate this inconvenience, the floor of the gangway from front to back of each room is formed of steps pivoted on beams, which are adjusted by the conductor to the required inclination by means of a lever. The cabins are so arranged that in their position of mean inclination, namely at the first platform, the fixed floor is practically horizontal, so that the total change of inclination is divided equally and in opposite directions between the lower and the upper portion of the journey. The movable steps being adjusted by the lever to the horizontal position form an actual stairway, downwards or upwards according to the direction of inclination of the cabin. The seats and their backs are rounded, so as to afford suitable support to the body in all positions of the cabin on the inclined track. The conductor's place is under cover, in front of the lower room of the cabin, whence by the handwheel W, Figs. 11 and 26, he can regulate the motion of the lift by means of two ropes working over pulleys, and controlling the lever L of the water distributor, Fig. 19, Plate 69; the controlling gear is shown in Figs. 23 to 26, Plate 71.

Water Distribution.—The two ends of the hydraulic cylinder, Fig. 14, Plate 68, are connected by a circulating pipe C of 9 inches bore, at the bottom of which is placed the water distributor D, shown in Figs. 19 to 22, Plates 69 and 70. For lifting, Fig. 22, the water pressure is admitted into the top end of the cylinder, while at the same time the discharge from the bottom is opened. For lowering, Fig. 21, communication is opened between the top and bottom of the cylinder, so that the pressure has access to both sides of the piston, and the water simply passes from the upper to the under side of the piston through the circulating pipe.

When the lift is at rest, Fig. 19, no water is either admitted or allowed to circulate.

The water distribution is effected by means of an upright cylindrical valve-chest 9 inches diameter inside, Plates 69 and 70, in which works a hollow cylindrical slide-valve S, and also on the same spindle a double piston-valve P packed with cupped-leathers. Two pairs of facing ports in the upper part of the valve-chest are controlled by the slide-valve S, and communicate respectively with the pressure supply and through the circulating pipe with the top of the main cylinder. The double piston-valve P controls a lower port, which communicates with the bottom of the main cylinder; and below the piston-valve the bottom of the valve-chest is left open for the discharge of the exhaust water. When the double piston-valve entirely covers the lower port, the slide-valve at the same time covers the upper ports, as shown in Fig. 19; the water cannot circulate, and the lift is stopped from moving. When the valve is raised, Fig. 22, discharge takes place from the bottom of the hydraulic cylinder, while pressure is admitted to the top, and the cabin rises. When the valve is lowered, Fig. 21, the discharge from the bottom is stopped, but the water can circulate more or less freely from the top to the bottom of the hydraulic cylinder through the interior of the hollow slide-valve S; and the descent of the cabin is effected by its weight, which raises the movable-pulley truck as well as the main piston.

The power required to work the valve of the distributor under pressure is about 8,800 lbs.; and to save having to do this by hand, an auxiliary motor is attached to the distributor, Plates 69 and 70, consisting of a piston-valve V $1\frac{3}{4}$ inch diameter, which applies the water-pressure to an 11-inch piston M fixed on the valve-spindle of the distributor. The auxiliary motor thus controls the distributor, just as the distributor controls the main hydraulic cylinder.

At each end of its journey the cabin is stopped automatically by means of an ear or lip E, Fig. 18, Plate 68, fixed on the piston of the main hydraulic cylinder, whereby the aperture of the port in either end of the cylinder is throttled just as the piston is reaching

the end of its stroke. On the top of the piston is a small air-valve A, Fig. 18, which is opened by the pin X (Fig. 13) depressing its tail when the piston reaches the top of its stroke; the air so liberated escapes into the small chamber in the cylinder cover, Fig. 13, whence it is discharged whenever required by opening the air-cock J. To prevent the pair of long piston-rods from sagging, they are made to work through a sliding spider, consisting of a dummy piston U inside the cylinder and a sliding block B above, which are coupled together by a piston-rod of half the length of the main piston-rods, Plate 68; the spider thus travels up and down through half the length of stroke of the working piston, being pushed upwards by the latter and downwards by the movable-pulley truck.

Safety.—It was indispensable with this kind of lift to provide against possible breakage of the ropes. A safety brake with automatic clutches, Plates 73 to 75, has accordingly been applied to the truck carrying the cabin, and also to the counterweight truck, the principle being the same in both cases. On each side of the cabin truck and alongside the rail head are a pair of sliding shoes SS, Fig. 36, facing each other so as to grip the rail head between them; they are carried on a separate lorry L, Figs. 34 and 35, which is hinged at Z to the lower end of the cabin truck, Fig. 11. The shoes are embraced by three separate weights W, of which the two lower are free to slide upon their centre rod; and the shoes are tightened upon the rail head by three wedges working inside the weights. The bottom wedge is single, and thrusts upwards into the underside of the bottom weight; the two upper wedges, intermediate between the weights, are double, each thrusting first downwards into the weight below it and then upwards into the weight above. When out of action, the weights rest on the crossbars of the lorry, while the two upper wedges are withdrawn by springs, and the bottom wedge by the lever V, Fig. 34, which is centred in a lug projecting from the bottom weight; the shoes then run free with 1–8th inch clearance on each side of the rail head.

The six ropes are attached in three pairs, not direct to the cabin truck itself, but to opposite sides of three central rocking plates R,

each of which is mounted upon two axes fixed in the framework of the truck, underneath the cabin, as shown in Figs. 29 to 32, Plate 73, and in Fig. 37, Plate 75. Two slots in the plate, forming arcs of circles, allow of its rocking upon either one of the two axes; and when it does so through the breaking of the rope on either side, as shown in Fig. 31, a pin projecting from behind the plate and working in one of the slots in a vertical slide-bar B depresses the bar, thereby depressing also the arm A of a bell-crank lever, Fig. 37, and releasing the catch C which has retained in a state of compression a set of plate-springs pressing downwards on the top of the crossbeam M, Fig. 29. Through the lever V, Figs. 29 and 34, the plate-springs on liberation drive the bottom wedge upwards into the bottom weight, and tighten the shoes upon the rail. The bottom weight and shoes are stopped by the friction; and the descent of the cabin still continuing brings the middle wedge and finally the top wedge into action, each wedge in its turn increasing the pressure of the shoes on the rail. The result is that the cabin is stopped in a few seconds. Not only breakage of a rope, but even its mere stretching to any unusual extent, is enough to bring the brake into action through this arrangement of rocking plates and connecting gear. After the brake has been in action, the safety apparatus is reset by means of a screw and hand-wheel H, Fig. 37, by which the plate-springs are compressed sufficiently for the catch C to be caught and held up by the bell-crank lever A.

Should all the ropes happen to break simultaneously, as soon as ever the speed of the falling cabin exceeds ten feet per second it will at once bring into action a centrifugal governor, fitted within the wheel K at the top end of each brake lorry, Fig. 11, as shown in Figs. 38 to 41, Plate 75. The two serrated segments GG flying apart with the increasing speed, one or other of their teeth will strike the trigger T, and release the latch D, Fig. 38, thereby liberating the helical spring P, which by means of the slotted rod Q lifts the arm N projecting from the back of the horizontal shaft F; an opposite arm projecting from the front of the shaft depresses the arm A of the bell-crank lever, and thus releases the catch C and liberates the plate-springs, by which the brake is then brought

into action as before. In ascending faster than ten feet per second, the backs of the teeth in the centrifugal segments will merely trip the trigger T, which is loose in rising, and therefore does not then act upon the latch D.

The safety apparatus, which has never been used before, has been especially designed for these tower lifts by Mr. T. E. Brown, Jun., engineer-in-chief of Messrs. Otis Brothers and Co., by whom also the construction of the lifts was designed and superintended.

Edoux Lift. (Plates 76 and 77.)

The Edoux lift is widely employed in Paris, the most important example hitherto constructed having been erected there in 1878 in one of the towers of the Trocadéro Palace. The cylinder is vertical and about 230 feet long, necessitating the excavation of a deep pit to receive it. For balancing the lift very large ropes are required, inasmuch as they have to be equal in weight to half the volume of water displaced by the piston.

In the lift at the Eiffel tower, between the second and third platforms, both the above inconveniences have been obviated by an ingenious arrangement. Instead of effecting the ascent of 526 feet in a single flight, which would have been difficult to manage and sadly inefficient, the trip has been divided into two equal flights by a midway platform, Fig. 42, Plate 76; and there is one cabin for each flight. The two cabins counterbalance each other, being connected by means of four steel-wire ropes, which pass over pulleys above the third main platform. One cabin travels up and down the lower half of the trip, a height of 263 feet, whilst the other travels through the same distance in the upper half. Travelling in opposite directions, the two cabins thus meet and part at the midway platform, where the passengers brought up by the lower cabin change into the upper cabin, in which they complete their upward trip to the third main platform; while those brought down by the upper cabin change into the lower for descending to the second platform.

The two cabins are both guided by one central vertical column extending through the whole 526 feet height of the lift; and also by two smaller columns, each of which is half this height, one rising from the second main platform to the midway platform, and the other from the midway platform to the third main platform. The upper cabin is carried on two hydraulic rams of 12·60 inches diameter, working in cylinders HH of 14·96 inches diameter, Plate 76. To shelter them from the action of the wind, the rams are arranged to work within the upper guiding columns, within which also work the ropes that carry the lower cabin. The cylinders and rams are of steel plate riveted, except a portion of the length of the rams, which is made of cast iron, in order to obtain the extra weight necessary for lifting the suspended cabin with its passengers. The bottoms of the hydraulic cylinders hardly protrude below the floor of the second main platform.

Balance.—The sectional area of each ram is 124 square inches, or 248 square inches for the two; and their weight is 42,330 lbs. Supposing the lower or suspended cabin to be empty and to balance only the dead weight of the upper cabin, and that the latter be loaded with 8,800 lbs. weight of passengers, then in starting from the midway platform the pressure required under the rams to correspond with the unbalanced load should be equal to 42,330 + 8,800 = 51,130 lbs. The water being supplied by a reservoir 526 feet above the bottom of the cylinders gives a pressure of 228 lbs. per square inch at starting. On the combined area of the two rams the total pressure accordingly amounts at starting to 228 × 248 = 56,550 lbs.; and the difference, or 56,550 − 51,130 = 5,420 lbs., represents friction and loss of head. As the rams rise out of the cylinders, their weight increases while the head diminishes; but the balance is maintained by the increasing length of the ropes on the other side.

Safety.—The four ropes weigh together $53\frac{3}{4}$ lbs. per foot, or $53\frac{3}{4} \times 526$ = 28,270 lbs. for the total height. Their net sectional area is about $15\frac{1}{2}$ square inches. Taking the weight of the lower

cabin full of passengers at 18,740 lbs., the maximum load to be supported by the ropes is 28,270 + 18,740 = 47,010 lbs. or 21 tons, while their aggregate breaking strength is upwards of 500 tons. Hence the apparatus is perfectly safe.

Backman Brake.—In order to dispel all misgivings, the Backman brake, Figs. 43 to 46, Plate 77, will be applied on each side of the suspended cabin. In this plan a drum D turning on a vertical spindle works up and down within each guiding column G of the lower cabin, like a long-pitch screw in its nut, being threaded helically so as to gear with a corresponding helical rib H formed round the inside of the column. Round the drum thread are spaced a set of four rollers R running on the rib, which enable the drum to accompany the cabin up and down with scarcely any resistance. The top of the drum is turned conical, to fit into a corresponding hollow cone C turned in a bracket attached to the cabin. Should the cabin fall, it would quickly overtake the drums, because the latter have to run down their helical paths, while the cabin is falling vertically; the cones then coming into contact would cause friction enough to stop the drums from rotating; and the drums being thus locked in the columns would support the cabin and prevent its falling further.

PUMPS.

Water under pressure is the only motive power combining the precision and the ease of management required for lifts; and accordingly all the Tower lifts are worked by water, which is supplied by pumps placed in the bottom of the south pier, Fig. 47, Plate 77. Those by which the four ground lifts are fed pump the water through a pipe of 9·84 inches diameter into two cylindrical tanks, each 9 feet 10 inches diameter and 23 feet long, placed on the second platform. The two tanks are connected together by a pipe 19·69 inches diameter, from which four branches are led down to supply the cylinders at the foot of each pier. On leaving the cylinders, the water returns through underground pipes into

the feed tank at the south pier, whence it is pumped anew into the upper tanks.

The Edoux lift is supplied by two Worthington pumps, which deliver the water into a tank 9·84 feet diameter and 13 feet deep, placed on the third platform, Plate 76. A similar tank on the intermediate platform receives the discharge water, so that the pumps take their water from a height of 656 feet and deliver it to a height of 918 feet. The cast-iron pipes are made extra strong to resist so great a pressure.

Work Done and Consumption of Water.

Each of the Roux lifts consumes 1,925 gallons of water per trip, or the two together 3,850 gallons. Each Otis lift consumes 1,728 gallons per trip, or the two together 3,456 gallons. The four lifts together consume therefore 7,306 gallons in one minute, since each of them takes one minute for the ascent; this is equal to 121·8 gallons per second.

The difference of level between the pumping tank at the south pier and the supply tanks on the second platform is about 443 feet, after adding the loss of head. The power absorbed during the ascent of the four lifts from the ground level is thus equivalent to $\frac{7306 \times 10 \times 443}{33{,}000} = 980{\cdot}7$ horse-power, or say 1,000 horse-power.

The Edoux lift consumes 31·69 gallons per second. The difference of level between the two tanks, adding the loss of head, may be estimated at 393·7 feet, which will give for the power exerted in the ascent $\frac{31{\cdot}69 \times 60 \times 10 \times 393{\cdot}7}{33{,}000} = 227$ horse-power.

The combined power thus amounts to over 1,200 horse-power, which however is in reality exerted only at intervals, namely at the times of the ascents, that is to say for about one-fifth of the time occupied in making the complete trip up and down. The power is accumulating in the tanks during the stoppages and descents, and consequently less than 300 horse-power is required to be developed continuously by the pumps.

The Roux lifts consuming 3,850 gallons of water per trip take for their twelve trips per hour $3{,}850 \times 12 = 46{,}200$ gallons per hour.

The Otis lifts consume 3,456 gallons per trip, or for their eight trips per hour 3,456 × 8 = 27,648 gallons per hour. The total quantity of water required is therefore 73,848 gallons per hour, or 20·5 gallons per second, to feed the four lifts ascending from the ground.

The two pumps furnishing this supply, Fig. 47, Plate 77, each deliver 11 gallons per second at their ordinary speed, and at a higher speed are capable of supplying 18 gallons per second. The steam cylinder employed to work each pump has the Wheelock valve-gear, and is 23·6 inches diameter with a stroke of $3\frac{1}{2}$ feet; it works direct a horizontal double-acting plunger on the Girard plan, 11·4 inches diameter. These engines were constructed at the Quillacq works at Anzin.

The two Worthington pumps for the Edoux lift are driven by two tandem compound cylinders, Fig. 47, Plate 77. Together they supply 9·68 gallons per second at their ordinary speed, corresponding with a consumption of 34,862 gallons per hour. The volume of water required for each ascent is the product of the joint area of the two rams, or 248 square inches or 1·72 square foot, multiplied by the height of the half-lift or 263 feet; it is therefore 453 cubic feet, or 2,825 gallons. The total volume consumed for the twelve ascents made in an hour is therefore only 2,825 × 12 = 33,900 gallons.

A range of four Collet safety boilers is placed underground at the south pier, Fig. 47, Plate 77, near the steam pumps. Each boiler is capable of generating 3,300 pounds of steam per hour at a pressure of 140 lbs. per square inch. Three boilers are sufficient for driving the pumps in full work: the fourth is kept in reserve.

Discussion.

M. EIFFEL, whose remarks were kindly translated by M. Brüll, Past-President of the Société des Ingénieurs Civils, said that, in dealing with the results of the actual working of the lifts, which had not yet been got to work at the time of preparing the paper just read, he purposed enlarging upon the points most likely to be criticised, inasmuch as criticism was more valuable to the engineers of such works as these than unqualified approval.

With respect to the pumping machinery, its working was giving complete satisfaction, alike in the case of the Wheelock engines constructed at the Quillacq Works at Anzin, and in that of the Worthington pumps. The same was true of the Collet multitubular boilers, which somewhat resembled the Belleville boilers. There was also a very light and compact high-speed engine of 60 HP., driving a dynamo for electric lighting, and made by MM. Sautter Lemonnier and Co., which thus far was giving good results.

The Roux Combaluzier and Lepape lift was giving almost complete satisfaction; it was working well, and was easily kept in order. The only objection that could be made against it was that it was rather noisy; the chains of jointed rods running in the guide-trunks made more or less noise, which was augmented by the resonance of the hollow trunks themselves; but as the lift was working in the open air and at an exhibition, the noise did not matter much there, though in a house or other closed building it could not be used in its present form on this account. It possessed a great advantage in the fact that not only was it rendered absolutely safe by the very mode of its construction, so that no fall could possibly occur, but also its safety was apparent, and all who saw it, however ignorant they might be of mechanical engineering, felt satisfied that they were in a sort of carriage not very different from what they were accustomed to. It was therefore largely used by the public, who manifested no apprehension in regard to its safety. It was intended to carry 100 persons at once, and had often done so, making with this full load twelve double journeys in an

(M. Eiffel.)
hour; the pair of lifts thus enabled 2,400 persons per hour to ascend to the first platform with great safety.

The Otis lift was well known, not only in the United States, but also in England, and was beginning to be adopted on the Continent. It had the great merit of being so silent in working that it could scarcely be heard at all; and its motion was remarkably smooth. It was giving great satisfaction, notwithstanding a miscalculation as to its carrying capacity. It had been intended to raise fifty persons at a time, at the high speed of 394 feet per minute; but the number of passengers had not exceeded forty at a time. At first the number had been only thirty, but as the working had improved it had now risen to forty, and would perhaps reach forty-five. One of the principal reasons of this difference was that the weight of the cabins was considerably greater than had been anticipated, and consequently required heavier counterweights also; while at the same time there was some deficiency of working pressure, which he wished had been met by a rather larger diameter of the hydraulic cylinders. An improvement however would shortly be effected, by doing away with the upper cabin of each lift, and replacing it by an imperial, so as to diminish the dead weight of the cabin. As soon as this was done he expected the lift would give entire satisfaction to the public, as well as to all concerned in its working, by the smoothness and silence of its motion. The steeper inclination of the track between the first and second platforms, approaching the vertical near the top, presented a difficulty which it had at first been thought of meeting by some mode of balancing the cabin on jointed rods, so that its floor should remain always nearly horizontal. It was soon seen however that any such plan would involve a considerable amount of complication; and the next idea therefore was to keep the floor alone horizontal, instead of the whole cabin itself. For this purpose the floor had at first been constructed in a series of segments forming an inclined plane, which were severally kept horizontal by a mechanical adjustment, so that they then formed a sort of staircase when the cabin tilted either way from its mean position. Thus in quitting the lift at the top or bottom of its journey, there was a staircase to descend or ascend respectively. In practice this plan had not answered, and had been

attended with serious inconvenience; the steps were not steady enough to feel safe to the passengers, who also could not stand firm upon them, and ran the risk of being thrown over by their adjustment during the travel of the lift. Ultimately it had been found better to do away with these adjustable steps, and substitute a plain fixed flooring, with a few cross strips of wood for affording a foot-hold when it sloped up or down as the lift tilted one way or the other.

The Edoux lift, from the second to the third platform, had a pair of cabins working vertically and balancing each other. Its general working was giving satisfaction, and the motion being very smooth and free from jolts was highly appreciated by the public. As the lift rose, and the view through the framework of the tower became more and more extensive, the sensation was just the same as that of going up in a balloon; the motion was so steady that none of the passengers had experienced any giddiness or alarm. When carrying the full complement of 63 persons, the speed was less than had been desired; instead of 177 feet per minute as intended, it was scarcely 108 feet. The number of persons who wanted to go to the top of the tower was much larger than had been reckoned upon; and this reduction in the carrying power of the lift was therefore all the more disappointing; had the lift admitted, almost all the visitors to the tower would have gone up to the top. At the present time there was consequently some inconvenience from the number of passengers, who had to wait long for their turn; but improvement was daily taking place, and last Sunday as many as 4,200 persons had been taken up in seven or eight hours; a much greater number he hoped would yet be carried in the time. The deficiency in power was perhaps due to not having allowed enough for loss of head in the water pipes, which in some places were of too small diameter. Moreover the same pipe which rose from the pumps to the distributor on the midway platform was continued upwards to the upper tank on the top platform, so that the hydraulic rams when rising were supplied with water not only by the pumps, which still continued working and were then forcing an ascending column of water up direct to the distributor, but at the same time also by the descending

water from the upper tank. There were thus two opposite currents in the same vertical pipe, one upwards and the other downwards, which encountered each other at the point where they both had to enter the right-angled bend leading to the distributor; and the result must certainly be a serious loss of head. It would probably be found advisable either to increase the diameter of the pipes leading to the distributor, or else to carry the rising main from the pumps right up to the top tank at once, and not to the distributor at all, and to supply the latter direct from the top tank alone, so as to obviate the inconvenience of the two opposite currents meeting each other. With this exception, the lift was a very good one; it was particularly safe, because its safety was provided for in more ways than one. In the first place there were two independent cylinders and rams, so that no accident to either would affect the other. Secondly the ropes, in consequence of having to balance the increasing weight of the rams as the latter rose out of their cylinders, were made much larger than would be requisite for merely carrying the weight of the loaded cabins. There were accordingly four steel-wire ropes for connecting the cabins, and their aggregate breaking strength was 500 tons. As a still further precaution it had been thought necessary to provide also the small special brake described in page 362; but as here applied this had not been found satisfactory in working, because the connection of the cabin with the screwed drum working inside the guiding column necessitated an open slot running all down one side of the column; and the rollers round the revolving drum, as they successively crossed the slot, produced a series of unpleasant bumps which tended to twist and bend the drum, and rendered it a disadvantage in regard to safety, instead of an advantage. This objection was going to be obviated by doing away altogether with the rollers round the drum, and letting the external thread on the drum rub direct upon the internal thread in the column, like an ordinary screw in a nut. The brake itself however was really of little practical value, in view of the great margin of safety already secured by the excessive strength of the ropes, which moreover were made in duplicate, so that if one pair failed the other pair would still be sufficient to support the cage.

While thus pointing out the improvements yet desired and the slight imperfections at present met with, he wished to say that on the whole the lifts were working satisfactorily and with great regularity.

Mr. William Frank Hall, representing the makers of the Otis lift, believed that as a piece of engineering work the lift in the Eiffel tower was entirely unique. With regard to the statement that the lift was carrying only about forty persons, instead of fifty as intended, he explained that owing to a misunderstanding there was a deficiency of $1\frac{1}{2}$ atmosphere in the working pressure available upon the 1,134 square inches of piston area. The lift was now carrying an average of forty persons besides the two conductors, and had actually carried forty-six, representing an efficiency as a machine of about 80 per cent.,* of which in that extraordinary work there was reason to be proud. The question of speed when carrying that load had not been raised; it was entirely satisfactory.

The provision made for adjusting the steps forming the gangway in the cabins had been found in practice to be unimportant. Before the elevators were in operation it had appeared to him that the difference in inclination would be serious and objectionable; but as shown in practice at the present time it was not objectionable at all. The feeling of unsteadiness referred to by M. Eiffel arose from the play in the mechanism, which could not well be avoided. The passengers were always impatient to arrive at their destination and to get out of the elevator, and would step upon the inclined floor before the car stopped, thereby rendering it difficult for the conductor to adjust the inclination. The original plan had therefore been abandoned, and a fixed gangway substituted, which relieved the car of 700 lbs. weight; and as the unbalanced weight of each car was even then more than 4,000 lbs., this saving was an important consideration.

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* In a test made by M. Eiffel on 8th July of the Otis lift in the north pier, it lifted to the second platform a load of 7,550 lbs., or fifty persons averaging 151 lbs. each, showing an efficiency of 81·7 per cent.

(Mr. William Frank Hall.)

These elevators had been subjected to the most thorough testing. Each car with its accessories made up a weight of nearly 24,000 lbs. when empty; this he considered was far too heavy, but the cars were not made by his firm. Each car was loaded with 73 cwts. of pig iron, and raised 30 or 40 feet from the ground. In the test of the car in the north pier, the wire-ropes were disconnected and hempen ropes attached, which at a given signal were cut and the car was allowed to drop. It descended between 11 and 12 feet before the compound brakes acting upon the rails overcame the momentum of the mass; and then the car was arrested without any shock whatever, not even cracking the glass in the cabin windows. That was a test which had been made before the committee of the Exhibition who were in charge of the works. It was entirely satisfactory to find so ponderous a body falling to the extent of only 11 or 12 feet and then gradually stopping. In a similar test made by the same committee of the other car in the south pier, the cabin stopped in eight inches without any shock, the safety apparatus having been adjusted to stop it in that short distance. Although there had been no misgiving in his own mind as to the efficiency and safety of the lift, he believed that those who witnessed the test were a little uneasy.

The President asked for an explanation as to the deficiency of 1½ atmosphere in the pressure available for working the lift.

Mr. Hall explained that his firm had purposed bringing into use here a plan which they had generally adopted in America for large offices and other buildings where there was a varying duty, namely to pump the water into a closed tank for working the lift, instead of into an open tank; and it was intended that the closed tank should contain compressed air of 1½ atmosphere pressure, which would have enabled the lift to carry fifty persons easily. In their recommendation as to pumping power they had suggested the use of a Worthington direct-acting pump, which would have enabled the compression of the air to be perfectly controlled; but in the concession by the government to M. Eiffel it had been stipulated that all material

entering into the construction of the tower should be of French manufacture. The consequence had been that a French fly-wheel pump was used, which did not admit of sufficient control being exercised over the pumping, and there was danger of the air-pressure being exceeded. It had therefore been impossible to make a satisfactory trial of the compressed-air plan, and the lifts had to be worked by the hydraulic head alone, without the addition of $1\frac{1}{2}$ atmosphere of compressed air as intended when the machines were constructed. As however the machines were constantly improving in their working, he believed that in three or four weeks' time they would be carrying fifty persons besides the conductors, without the extra $1\frac{1}{2}$ atmosphere of pressure.

The President asked for some further explanation as to the way in which the safety clutch came into operation in the Otis lift. On the previous day he had gone up in the lift, and had observed only the slightest sensation produced in changing the angle of inclination. It was not at all disagreeable, and the seats were comfortably shaped at the back, so that only a slight additional pressure was felt, or a little relief, according as the lift was ascending or descending.

Mr. J. R. Furman, one of the engineers in charge of the construction of the Otis lifts at the Eiffel tower, explained that each of the three pairs of oscillating plates to which the ropes were attached underneath the lift was held central in the regular working by the equal pull of the pair of ropes attached to it on opposite sides. If either rope stretched more than the other, or broke, the oscillating plate was tilted out of centre towards one side or the other; and the elliptical safety-springs, being thereby liberated, acted through the connecting levers upon the wedges of the safety clutches, and caused these to grip the rail between them with a force increasing so rapidly as to stop and hold the lift within a very short distance of fall.

Mr. Druitt Halpin considered the means taken to test the Otis lift, as described by Mr. Hall, were a very necessary precaution. In

(Mr. Druitt Halpin.)
some passenger lifts which he was having constructed for carrying large numbers of persons, though not on so large a scale as at the Eiffel tower, he was taking one precaution which he hoped would be useful, whether novel or not. Instead of releasing the lift in the way described, by lashing it up at a particular place with ropes and then cutting the ropes, it was specially fitted with releasing gear, which could be tripped at any point. When loaded with pig iron to its full load, it would be run down at full speed, and tripped at any place desired, whereby the efficiency of the safety apparatus would be thoroughly tested.

Mr. R. E. B. Crompton said a point of great importance had been touched upon by M. Eiffel in his statement that there had been a loss of expected head of water for working the Edoux lift on account of the interference of the two currents, one descending from the storage tank at the top of the tower, and the other rising direct from the pumps themselves. This was interesting to electrical engineers who had tried to explain electrical conditions by hydraulic analogy; for that analogy appeared to fail in this special case. Electrical engineers were accustomed to supplement their supply of energy derived directly from the source of power—the steam engine or other motor—by means of accumulators; and it was actually found that there was no loss of head whatever in any part of the circuit when those two supplies met in the conductor, and when they were used, according to the French expression, "in derivation." But with water it appeared in this particular instance there was such a loss; and it therefore appeared that water could not be used from accumulators at the same time that it was being used from the motor itself or the direct source of supply, without a loss of efficiency in comparison with the efficiency realised when using water from one source only. This was a consideration which directly affected hydraulic transmission, and should be taken note of in that connection.

Mr. Arthur Paget, Vice-President, suggested that the reason why one current of electricity impinging upon another did not cause

much loss of power, whereas if one current of water impinged upon another it caused a considerable loss of power, might probably be rendered more intelligible by carrying the illustration a little further, and imagining one current of thick treacle or heavy tar impinging upon another, when there would naturally be a still greater loss of power. The difference in viscosity and weight or momentum and inertia between water and thick treacle or heavy tar was probably not so great as the difference in viscosity and momentum and inertia, or in want of power of fluid flow and of facility for sudden changes of the directions and speeds of flow, between water and electricity.

Mr. CROMPTON was afraid the matter was not to be explained in so simple a way; he wished it could be. Electricity appeared to be not a material substance like water or treacle, but a state or condition of matter; and an electrical current was the transmission of that state of matter, and not a current of matter itself.

Mr. HALL said that in a great many of the Otis lifts, where the water had to be pumped up direct into the storage tank at top, it was the practice for the supply pipe from the tank down to the cylinder to be used also as the rising main; and he had noticed no material loss of power. When pumping into the open storage tank at an elevation of 100 feet, for instance, a large pipe was carried up from the pump to the head of the cylinder, and an air chamber was there formed of 6 or 8 feet more of pipe, closed at the further end; and from the cylinder head the pipe was continued upwards, but about a foot to one side, up to the top tank. Less than half the supply for working the lift was drawn from the top tank, the rest being supplied by the pump direct. If there had been any material loss of power in this mode of working, it would certainly have been noticed during the fifteen years it had been in use; but it had never been brought to his attention as of any moment whatever.

The PRESIDENT enquired whether any difference had been found between pumping into an open storage tank, with an air-vessel at the cylinder head, as now described, and pumping into a closed tank

(The President.)
at top, according to the plan already mentioned for getting the extra pressure that had been intended for the lift at the Eiffel tower.

Mr. HALL replied that he had never found any difference. In New York city there were five thousand elevators, for all of which the water had to be supplied to the top storage tank by pumping.

The PRESIDENT asked whether the ascending pipe was always made to serve as the descending pipe also.

Mr. HALL said not always, but often, especially where there were large plants and two hydraulic cylinders placed side by side. The plan of compressing the air in a closed storage tank was not one in common use; it was intended only for individual cases, as at the tower, or as in the Produce Exchange at New York, where there were nine passenger elevators carrying 25,000 people a day. As there were 3,000 members at the Exchange, there was a great rush at ten o'clock and two o'clock, and the lifts often carried thirty or forty persons; the pressure in the tanks was accordingly increased perhaps 20 or 25 lbs. per square inch shortly before those times. The demand ceased in half an hour, and then the ordinary service went on without the compressed air.

Mr. SCHÖNHEYDER pointed out that the same plan of using only a single pipe was generally prevalent for the supply of towns with water, where the ascending main was made to serve also as the descending main. The water being pumped through the main into the reservoir was sometimes flowing up into the reservoir, and sometimes back from the reservoir to the houses, according to the requirements of the supply; and it appeared to him impossible that any loss could take place in that plan.

In preference to any arrangement for tilting the floor of the Otis lift during its ascent and descent in the Eiffel tower, he considered it would be much better to keep the floor perfectly horizontal throughout the journey. The arrangement for doing so seemed so obvious that he wondered why it had not been adopted. If instead

of only one pair of rails at the back of the lift, with four wheels running on them, there were two pairs of rails, back and front—the back pair for carrying wheels fixed on the back bottom corner of the cage, while a pair of wheels on the front top corner of the cage ran upon the front pair of rails, of slightly different curvature from the back rails—the arrangement would be as simple as at present, and the effect would be that the cage would travel with its floor perfectly horizontal all the way.

For the pumping arrangements there were two distinct kinds of pumping engines, the Wheelock and the Worthington; and as they were both worked from the same boilers, it would be interesting if experiments could be made with regard to their relative consumption of fuel.

Mr. FURMAN explained that the principal reason for not adopting the plan suggested for keeping the car always level was the great additional cost it would have involved, as it would have been necessary to have an additional rail in front of the car and an additional girder to carry the rail. The weight of the car would also have been greatly increased by the balance gear which would then have been required.

Sir JAMES N. DOUGLASS, Vice-President, asked whether any observations would be made with regard to the rigidity of the magnificent structure in which these lifts were working, and as to the amount of its vibration under different wind pressures. This was a matter of great importance not only for lofty buildings generally, but for many other erections; and here was now an admirable opportunity for ascertaining the exact vibration of such a structure under the various wind pressures to which it must be exposed. The subject was one that had received attention in many directions, in regard to bridges and other structures. In lighthouse towers he had himself observed, by means of a plumb line suspended from the top, that the oscillations were not rectilinear, forwards and backwards, but followed more or less an oval course in plan; and if any vibration was detected in the Eiffel tower he believed it would be

(Sir James N. Douglass.)
found to partake of that rotary character. No doubt M. Eiffel had had this matter under his consideration, and would be sure to give it his best attention, for which English engineers would hereafter have to thank him.

Mr. Benjamin A. Dobson, Member of Council, wished also to ask whether any observations had been made with regard to the effect of the sun's heat upon the south side of the tower, and whether there was any difference in the perpendicularity of the structure during the heat of the day and during the cool of the evening. He had heard it asserted that a difference in inclination had been observed in the tower during those periods.

M. Eiffel replied that there had as yet been no opportunity for making any observations on the stability or vibration of the tower, the whole time having hitherto been occupied in the completion of the structure itself. The effect of wind pressure had been calculated, and the conclusion had been arrived at that the deflection produced by a pressure of 20 lbs. per square foot would be about 6 inches at the top of the tower. No gale so violent had yet been experienced, but strong winds of 8 to 10 lbs. pressure had already occurred, under which no movement had been perceived. With gales blowing 56 miles an hour, such as had frequently occurred, the oscillations of the top of the tower were wholly imperceptible; even when leaning against the railing no horizontal tremor could be felt. A slight vertical tremor alone was felt when the lift was coming up. The workmen engaged in the erection of the tower had not felt any movement during the strongest gales. This was not surprising, inasmuch as, although the leverage was so great, yet the amplitude of the vibrations must be too small, and their period too long, for them to be felt more than in the minutest degree. Arrangements were now being made for endeavouring to measure the oscillations that must occur; he had tried a telescope, but had not succeeded in observing any movement with certainty, and was accordingly having a seismograph put up, by which he hoped any oscillations would be rendered perceptible. The instrument would consist of three

sensitive levers like pendulums, vibrating in three planes at right angles to one another, two of the planes being vertical and one horizontal; and the levers would record their vibrations upon three corresponding cylinders revolving on axes in the same planes. Just as the top of a poplar tree described more or less of a circle under the action of the wind, so he anticipated that the movement at the top of the tower would be found to take an oval course, as was the case in almost all such vibrations; the same held true also in bridge vibrations, which described an ellipse more or less elongated.

In regard to variation of temperature, no effect had been observed to be produced thereby, notwithstanding that great differences had occurred between the temperature at the bottom of the tower and that at the top.

Respecting electricity likewise there was nothing to report. This was just what he had been given to understand beforehand, as most electricians agreed there would not be much to observe, because the mass of the tower was so great, and its connection with the earth so perfect, that no electrical phenomena could occur. In some interesting experiments recently made on the connection of the tower with the earth, the observer had been so surprised to find no resistance that he was led to believe there must be some error in the observations; subsequently however he had satisfied himself that there was no such error, and that it was really the fact that there was no resistance at all. The tower was indeed a perfect reservoir of electricity; and it seemed very likely therefore that hardly any electrical phenomena could be observed. It was certain the tower must have been struck aloft in thunderstorms which had already occurred, but no one had been aware of it; and he had heard the remark made that any one up in the tower at such a time would certainly be struck, but would not feel that he was so. He was also reminded by M. Ansaloni that a thunderstorm had been seen all round the tower, while at the tower itself there was none; and on another occasion a thunderstorm approaching the tower had ceased on reaching it, but had resumed its activity after passing out of its reach. Thus the tower certainly produced a neutralising effect upon the storms, which were rendered imperceptible on the

(M. Eiffel.)
structure itself; and consequently no electrical phenomena had been observed upon it.

The President was sure the Members would join in thanking M. Ansaloni for his description of the lifts, the merits of which they would have an opportunity of appreciating during their visit to the tower on Friday; and also in thanking M. Eiffel for his interesting supplementary information on the subject. The discussion had been a valuable one, and had elicited information by which they would all profit. He proposed a hearty vote of thanks to both gentlemen.

THE ETHER-PRESSURE THEORY OF THERMODYNAMICS APPLIED TO STEAM.*

BY MR. J. MACFARLANE GRAY,
MEMBER OF COUNCIL OF THE INSTITUTION OF NAVAL ARCHITECTS.

In 1880 and again in 1885 papers were read by the author before this Institution * upon the same subject with which he now deals. In the latter paper it was mentioned that he could not then reconcile the Ether-Pressure Theory and the Second Law of Thermodynamics with the then universally accepted view of what non-perfect gas is. Since that date he has discovered that that view of gas is what has to be modified; and then the second law stands in perfect harmony with the ether-pressure theory. In the present paper he is unable to give all the details of the investigation; and as he is arranging to read papers on the same subject before other institutions, he thinks it best to give here only a popular introduction to the ether-pressure theory, and an account of what the form of the theta-phi diagram now is (page 411). As his first paper on this subject was, at his request, not included in the Transactions, it will be necessary now to run over the introduction then given, only altering it to conform with his present views.

Ether-Pressure is an idea as old as Greek science; and Newton believed it to be the cause of gravitation, but he did not publish any theory about it, "because he was not able from experiment and observation to give a satisfactory account of this medium, and of the manner of its operation in producing the chief phenomena of nature."†

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* This paper was read to the Institution of Naval Architects on 11th April 1889, and is here reproduced with their concurrence, and by permission of the author, by whom it has also been further revised for the purpose, as well as abridged by the omission of the portions which necessarily recur in his subsequent paper on the Rationalization of Regnault's Experiments on Steam (page 399).

† See Appendix, pages 394–398.

Since the close of the terrestrial chapter of Newton's life, the modern theory of thermodynamics, the atomic theory of chemistry, the kinetic theory of gases, the science of electricity and magnetism, the undulatory theory of light, the spectroscope, and the telephone have all been won by human thought. We are therefore today in a much better position for theorising on physical phenomena than Newton was. The author believes that, if Newton had with these advantages attempted the problem upon which he has himself been occupied so many years, he would have solved it completely in as many days.

Ether-Pressure.—The view according to which the investigations referred to in this paper have been prosecuted is, that every physical phenomenon is the immediate result of the pressure of an invisible and impalpable universal molecular ether upon the external surfaces of the molecules of ordinary matter. The pressure of the ether must be many millions of tons upon the square inch. To produce gravitation, Maxwell tells us that "if the ether is molecular, the grouping of the molecules must remain of the same type, the configuration of the groups being only slightly altered during the motion." In the author's paper in 1880 was given a long quotation from Locke's "Essay on the Human Understanding," in which he refutes the ether-pressure theory, as then understood, on the ground that, although such a pressure might prevent two bodies from being pulled apart in a direction normal to their surface of contact, it could not prevent them from being slid the one upon the other, and so separated in a direction parallel to that surface. It was not then known to the author that Locke and Newton were intimate friends: this he now knows, and therefore he now regards that quotation as being probably not altogether Locke's objection to the ether-pressure theory, but really the only published statement of Newton's difficulty. The difficulty as there stated is entirely overcome when the ether is considered to consist of separate particles of matter, each particle very much smaller than the atoms of the substances known to the chemist, but, however small, still in magnitude bearing a significant ratio to them.

In elementary thermodynamics it is proved that, if a body is in the form of a gas, its particles flying to and fro in all directions, then—if the magnitude of the particles be neglected, that is, if they be regarded as mathematical points, but yet really physical points, possessing impenetrability and the inertia property which characterises matter as different from space—the energy E of the to-and-fro motion must be numerically one and a half times the arithmetical product of the pressure p multiplied by the volume v. Each of such inertia points must therefore have on the average a play-space v numerically equal to two-thirds of the quotient of its energy E divided by the pressure p per unit of area, or $v = \frac{2}{3}\frac{E}{p}$. Call the particles of the ether *ethids*, to distinguish them from the atoms and molecules of ordinary matter; and let the ethids be considered as minute spherules. The same relation $v = \frac{2}{3}\frac{E}{p}$ must hold good for the ethids as for the molecules of a gas. What is the effect of the spherule magnitude in modifying the expression $v = \frac{2}{3}\frac{E}{p}$? It is evident that the volume denoted by v must be the dynamic volume only, namely that traversed by the centres of the ethids.

To make explanation simpler, let the molecule of a gas be regarded as having the form of a rectangular prism, say it is a minute brick of matter. At first let it be thought that the brick is battered by the ethids always at the same spots, and let there be at each of these spots a hollow or cup, so that the ethids when in collision with it have their centres in the plane of the rectangular surface of the brick. The formula $v = \frac{2}{3}\frac{E}{p}$ refers to the space traversed by the centres of the ethids: so that it is evident that the effective volume of the brick in the ether is that which includes these cups; and when two of these cupped bricks are brought together, the effective volume of the pair will be just the sum of their volumes singly. If the cups were planed off the two sides which are to be brought into contact, the effective volume of the pair when in contact would then be less by that amount than the sum of their volumes singly. If however the cups were planed off all the sides of the bricks, their effective volumes singly would be just the same as before, because the course of impact of each ethid would terminate

at the same point as before. And when the two bricks are in contact at one pair of sides, the total effective volume is just as much reduced as it was in the previous case. The total effective volume of two molecules of matter in the ether is therefore less when they lie in contact than when they are apart.

In his first paper the author gave the names for these volume differences, to which he will still adhere. The point at which the centre of an ethid is, when in contact with a molecule, is called the *meta*, meaning *turning point.* Meta was the name of the turning post in the Roman circus; and he has elsewhere shown that it stands in that sense in the naval architect's word, meta-centre. The surface which would contain all the metas is called the meta-surface; it is at a distance from the surface of the molecule equal to the radius of an ethid. The space between the meta-surface and the matter-surface of the molecule is called the meta-film of the molecule. The meta-volume of a molecule is the volume including the meta-film. The matter-volume of a molecule is the volume exclusive of the meta-film.

Gravitation.—The pressure of the ether is the immediate cause of gravitation. From this we can arrive at a measure of what the differences of ether-pressure must be as a minimum. How much greater than that minimum they may be cannot at present be determined. We know that matter can be at least as dense as platinum. Say that a bar of platinum, one inch square in section and equal in length to the earth's equatorial diameter of 7,926 miles, is going round the sun on the earth's orbit, with its length always radial to the sun's centre. The effective ether appulsion which produces the curvature of its path is 104 tons upon the square inch. [The calculation is as follows, taking 92,000,000 miles as the radius of the orbit, and 1,342 lbs. as the weight of a cubic foot of platinum. Effective ether appulsion or centripetal force in tons $= v^2 \frac{w}{r\,g}$; where v^2 = square of velocity in orbit in feet per second $= \left(\frac{\text{circumference of orbit}}{\text{seconds in one revolution}}\right)^2 = (2\,\pi\,r)^2 \div (365 \cdot 25$ days in a year $\times$ 86,400 seconds in 24 hours$)^2$; and r = radius of orbit in feet = 92,000,000 miles $\times$ 5,280 feet in a mile; and g = accelerating force

of gravity = 32·2 feet in a second; and w = weight of platinum bar = (7,926 miles × 5,280 feet in a mile ÷ 144 feet length to one cubic foot) × 1,342 lbs. per cubic foot ÷ 2,240 lbs. in a ton. Therefore $v^2 \frac{w}{r\,g} = \left(\frac{2\,\pi\,r}{365\cdot25 \times 86{,}400}\right)^2 \times \frac{w}{r\,g} = \left(\frac{2 \times 3\cdot1416}{365\cdot25 \times 86{,}400}\right)^2 \times$ $\frac{92{,}000{,}000 \times 5{,}280}{32\cdot2} \times \frac{7{,}926 \times 5{,}280 \times 1{,}342}{144 \times 2{,}240}$ = 104·12 tons per square inch as the centripetal force or effective ether appulsion.]

Ether Sub-pressure.—The ether pressure is diminished in the neighbourhood of any mass consisting of an aggregation of ethids, and the diminution is directly proportional to the mass and inversely proportional to the distance from the mean centre of the mass. This is what is usually called "potential;" it will be here called the *sub-pressure* of the ether. A diagram showing the variation of the sub-pressure along any radial line is the common hyperbolic curve. It is the slope of the sub-pressure which produces appulsion. In Fig. 9, Plate 79, the distance downwards below the curve SS is the ether-pressure. The upward distance between the curve SS and the radial straight line RR represents the diminution of pressure, or the sub-pressure. The line of zero pressure, to the same scale, is at a great distance down, probably at such a distance that the sub-pressure shown by the distance between the curve SS and the line RR is quite insignificant in comparison therewith.

There is no such action in nature as that action at a distance which is popularly implied in the word attraction. Newton asserted that there was not any such force.* The difference between $\frac{1}{\rho - \frac{1}{2}}$ and $\frac{1}{\rho + \frac{1}{2}}$ is $\frac{1}{\rho^2}$ when ρ is great: as is the case when ρ denotes the number of times that the length of a molecule of matter is contained in its distance from the centre of the sun or from the centre of the earth. This makes appulsion to vary inversely as the square of the distance. Gravitation effect is the differential of the ether pressure over the surface of the molecule; the differential of $\frac{1}{\rho}$ is $-\frac{1}{\rho^2}\,d\rho$, and therefore a minus pressure varying as $\frac{1}{\rho}$ becomes

* See Appendix, pages 395–396.

effectively a centripetal appulsion varying as $\frac{1}{\rho^2}$. If in Fig. 9 the tangent to the hyperbolic curve, or the slope of an element of the curve, is prolonged to the vertical axis at T, the line will rise by just the amount AT equal to what the ordinate was at the point E where the slope was fixed. There is a rise of 104 tons per square inch on 7,926 miles; and the solar sub-pressure at the earth—that is, the ordinate on the earth's orbit where the slope is taken—must therefore be $\frac{104 \cdot 12 \times 92{,}000{,}000}{7{,}926} = 1{,}200{,}000$: that is, $1\frac{1}{5}$ million tons on the square inch. The solar sub-pressure at the surface of the sun, whose radius is 425,000 miles, must be $\frac{1{,}200{,}000 \times 92{,}000{,}000}{425{,}000} = 261{,}630{,}000$: that is, say 260 million tons on every square inch; and this is to the total pressure of the ether no more than a wave trough to the depth of the Atlantic.

As the ether pervades the molecular interstices of all bodies, the pressure on any surface of any molecule is nearly balanced by the pressure on the opposite surface; and it is only the difference of these two that we can be experimentally cognizant of. On the earth's surface at the equator, bodies are subjected to a pressure which is more than 104 tons per square inch greater at midnight than at midday.

The quantity of matter in a body is, according to the ether-pressure theory, regarded as being merely the meta-volume or effective volume of its molecules, irrespective of any consideration of density; that is, recognizing only volume and not quality of substance. All matter is regarded as being merely aggregations of ethids; and the withdrawals of those ethids from the originally uniform ether medium cause the medium to be strained in the direction of the withdrawals, that is radially towards the centres of aggregation. The ethids are regarded as arranged according to a permanent type of grouping, so that the ether can be subjected to different stresses in different directions at the same place; in this respect ether is not like gas. Every spherical shell around a centre of aggregation would therefore be compressed tangentially, and extended radially inwards towards the centre; that is, its thickness would be increased while its external circumference would be

diminished. The tangential compression does not affect the force in the radial direction, but it maintains the equilibrium of the ether. The author does not attempt to deal with the constitution of the ether, or the nature of the motion of its ethids; he has referred to it merely to establish the magnitude of the ether pressure, and to show further on that it is sufficient to account for the disappearance of latent heat. Professor Clerk Maxwell and others have shown that such an ether medium would be stable, and that it would account for gravitation.

What has now been calculated is the solar sub-pressure. Similarly around the earth, and extending out into stellar space, there is also a terrestrial sub-pressure. A bar of platinum, 1 square inch in section and 144 feet in length, weighs 1,342 lbs. at the earth's surface. If placed vertically, the ether pressure must be 1,342 lbs. per square inch greater at the top end than at the bottom. The slope of the terrestrial sub-pressure per mile is therefore $\frac{1342}{2240} \times \frac{5280}{144} = 21 \cdot 967$, or say 22 tons per square inch. This, multiplied by 3,956, the earth's mean radius in miles, gives say 87,000 tons per square inch as the terrestrial sub-pressure of the ether at the surface of the earth.

The sub-pressures of different bodies are superposed without being in the least degree modified one by another. Every atom, as it was formed by aggregation of ethids, produced its own cosmical sub-pressure, by the vacation of their play-spaces and by the reduction of meta-film by the contact of surfaces in it. As atoms became molecules, and molecules concreted into blocks, the sub-pressures of each particle were added together; until, as in the solar sub-pressure, the total amounted to hundreds of millions of tons on the square inch. These rough calculations are given now, in order to make the subject less hazy than when mere generalisations are hesitatingly mentioned. These however are merely minimum limits; for, just in the proportion that absolutely solid matter would be of greater specific gravity than platinum, so must these differences of ether pressures be all increased. In approaching the Ultimate, we must never forget that there is really "no high, no low, no great, no small," but in our own thinking; and therefore pressures of

millions, billions, or even trillions of tons upon the square inch, on every face of every atom of matter, can be just as likely as not, until the contrary is ascertained to be true. The most stupendous forces dealt with by man, and likewise those so much greater revealed in physical astronomy, may be, standing out in this ether pressure, no more than wavelets upon the surface of a fathomless ocean, whose interweaving ripples make up man's phenomenal universe.

Chemical Affinity.—Having, from what is observed in gravitation, obtained a proof of the enormous magnitude of the pressure with which Nature works everywhere, we ought to be prepared to find that, in the aggregation of atoms, the magnitude of cancelled meta-film may bring about the realisation of an enormous expression of ether energy. It is also obvious that, when a multitude of similarly aggregated atoms is brought into contact with another multitude of different atoms, if these are violently shaken together, the two sets of molecules may exchange mates, if the meta-volume of the whole mass can be thereby reduced. The atoms may have many different forms, and the smallest atom may not have the smallest faces. This is the explanation of chemical affinity; minimum meta-film is the goal in every chemical action.

Combustion.—In the boiler furnace, the oxygen and carbon atoms go together with important diminution of meta-volume; and the energy of the ether expansion is then in the to-and-fro motion of the atoms in the molecule. In considering this to-and-fro motion of the atoms, it will be simpler to adhere to the brick form of atom; the same reasoning will apply to many other forms. The action is illustrated for maximum movement in Figs. 1 to 6, Plate 78. In Fig. 1 the bricks A B and C D are just touching at their B and C corners, and their total meta-volume is almost a maximum. Let the pair of bricks be then at rest, except relatively. They are being battered by ethids on all sides. They therefore cannot remain in this position, for the effective area of the D end is greater than that of the C end by the area of the cross-section of the meta-film on the

B side of C D; and similarly for the ends A and B. The pressure of the ether on an area equal to those cross-sections of meta-film propels the bricks together in the direction of the arrows; and the section of the meta-film multiplied by the travel of each brick upon the other is precisely the volume of meta-film cancelled upon each brick. They pass through phase 2 with great accelerity,* and in phase 3 their velocity is a maximum. The region of the ether has expanded by as much as the meta-volume has diminished; and the impetus or work done by the ether in its expansion is now in the relative energy of the bricks. That impetus carries them on through phase 4, but now with great decelerity,* for they are now expending their energy in compressing the ether as their meta-volume increases. In phase 5 they have again attained their maximum meta-volume, and are relatively at rest. In phase 6 they are again approaching in the opposite direction. The ethids are supposed to be grouped in a certain fashion, so that a compression of the ether at any place provokes an increased local pressure there as if it were a solid body. The effective force therefore increases with the compression, and in direct proportion to it in such an example as that now described. The reciprocating motion would therefore be isochronous; and the author suggests that this is the condition of glowing matter, as in the sun's photosphere or in flame anywhere. The length of travel however may be very small.

Radiant Heat.—Isochronous vibration sets up that palpitation of the ether which is called radiant heat; and at every stroke of the reciprocation less work is done upon the atoms by the ether than was in the preceding stroke done upon the ether by the atoms; because part of the work done upon the ether by the atoms is passed on by the ether immediately acted upon to the distant regions of the ether. The radiant state of gas is that in which the atoms of the molecules are relatively in motion. At a lower temperature the atoms are not in relative motion; and then the gas

* By accelerity is meant rate of acceleration, and by decelerity rate o retardation.

is not radiant, but it can by impact render radiant any solid containing it. That is, the molecules of solids and liquids are in continual reciprocating motion upon each other, as the two bricks which have just been described, but the length of travel is much less.

Cohesion.—This theory explains the cohesion of solids. The extension of a solid within its elastic limit is a minute sliding of all its molecules upon each other in the direction of the pull; and the work done upon the body in extending it is really spent upon the ether by increase of meta-film accompanying the extension. It is the same in compression; there is still an increase of meta-film and meta-volume.

Latent Heat.—Where does latent heat hide? When boiling water is evaporated at atmospheric pressure, say in an open vessel, the work done upon it over and above the boiling heat is what is equivalent to lifting the water 142 miles high. The heat due to the steam as a gas is about 38 miles of this height; and the latent heat proper, or that which is still hidden, is the other 104 miles; and there is perhaps 84 miles more for all the heat which was in the water before evaporation: say 226 miles altogether. All the work of the last two component items, making 188 miles of lift, is the *heat of segregation* or splitting heat; and is invested in the compression o the ether, by the increase of meta-film when the water molecules are parted from their liquid contact. The increase of exposed molecular surface when one rain-drop only is evaporated must amount to many square feet of area; and in the change of state there must be the same amount of creation of meta-film, and consequently the work of compression of the ether. When these particles come together again in condensation, the previously hidden energy reappears as heat.

Energy of Gas.—According to the notion of meta-film which has now been explained, the energy expended in raising the temperature of a solid or a liquid from absolute zero is accounted for by the continually increasing amplitude of the relative motion of its

contiguous molecules, which, sliding upon each other reciprocatingly, thereby increase the mean molecular meta-volume of the substance, and so compress the ether. When at last the extent of reciprocating travel has increased so much that the molecules part company, the initial step in evaporation has taken place; but the communication of the constitutional energy of vapour at that temperature has yet to be effected. What this constitutional energy of gas is will now be considered.

In works on thermodynamics it has often been explained how it is that the energy of translation in gas is one and a half times its $p\ v$. This is a beautiful flower, which every engineer should carry in a mental buttonhole. From the following explanation it may be obtained perhaps more easily than from other published statements.

The rate per second per square inch of surface at which momentum normal to that surface is changed is the pressure per square inch upon that surface in poundals; dividing by $g = 32{\cdot}2$ gives the pressure in pounds per square inch. If in a gas the particles and their motions are uniformly distributed throughout the volume, whether it be uniform order or uniform confusion, the components of the motions in any volume will be equally distributed in any three rectangular directions. Take the components of the motions towards any element of surface to be considered; and in these components let there be always a mass m per unit volume, moving with the component velocity u_1 normal to that element of surface. The component momentum of this mass is always $m\ u_1$; and if the particles are without magnitude, this mass m will be delivered upon the surface at the rate of u_1 times per second per square inch. If the particles had magnitude, the rate of arrival of momentum would be greater, because then they would not have to travel so far before they had arrived and had to be reversed. The rate at which that momentum approaches the surface is therefore $m\ u_1^2$, regarding the particles as without magnitude. This momentum is all reversed in impact. As the difference between receiving a sovereign and giving one away is two sovereigns, so the change of momentum of these particles in impact is $2\ m\ u_1^2$ per second per square inch of surface. When this is calculated similarly for all the lots of

particles separately, and the sum of all the various quantities of the form $m\, u_1^2$ is found and divided by the total mass w per unit volume, let the quotient be written $= \bar{u}_0^2$. This is called the mean square component velocity, and $\bar{u}_0$ is the velocity of mean square component. The pressure then, according to the previous statement, is $p = 2\, w\, \bar{u}_0^2$, in poundals per square inch.

Now for each of the quantities $m\, u_1^2$ normal to the surface considered, there will be an equal m with equal u_1^2 normal to each of the six surfaces of the cube. The sum of the squares of the actual velocities is equal to the sum of the squares of the component velocities for each m making up the total mass w per unit volume. Write now for the sum of the masses, each multiplied by the square of its actual velocity, $w\, \bar{u}^2 = 6\, w\, \bar{u}_0^2$, where $\bar{u}^2$ is called the mean square velocity, and $\bar{u}$ is called the velocity of mean squares. Since $p = 2\, w\, \bar{u}_0^2$, we have $3\, p = 6\, w\, \bar{u}_0^2 = w\, \bar{u}^2$; or pressure p in poundals $= \frac{w\, \bar{u}^2}{3}$; or pressure p in pounds per square inch $= \frac{w\, \bar{u}^2}{3\, g}$. Now w will increase along with v as the volume is taken greater; therefore $p\, v = \frac{w\, \bar{u}^2}{3\, g}$. Now energy $E = \frac{w\, \bar{u}^2}{2\, g}$. Therefore $E = \frac{3}{2}\, p\, v$; or the component energy in each of the three rectangular directions is $\frac{1}{2}\, p\, v$. If the pressure is different in different directions, as is supposed to be the case in the ether, the component energy in any direction must be calculated according to the component pressure in the same direction.

In this statement there has been no restriction about motions, except impartial distribution; and the particles have been considered to be mathematical points. If the ether is not continuous matter, this relation of $p\, v$ to energy must apply also to it when the magnitude of the ethids is neglected. In any vessel containing gas or steam, the gas would consist of a multitude of molecules fairly distributed through a much greater multitude of ethids, and the actual pressure would be one common to ethids and molecules. The apparent or effective pressure however would be the excess of that common pressure above the external pressure. The actual $p\, v$ of gas and ether would be two-thirds of the motion energy of both ethids and molecules. The mean play-space of any one ethid, or of

any one molecule, would be also determined by the relation $v = \frac{2}{3}\frac{E}{p}$, in which E would be the mean energy of that particle, and v its mean play-space. Although the play-spaces of each particle, whether ethid or molecule, are interspersed throughout the whole capacity of the vessel containing them, there is never any confounding of play-spaces. In order to simplify reasoning, we may therefore imagine, without ignoring any dynamical necessity, that all the gas molecules are collected at the right-hand end R of a cylinder, and all the ethids at the left-hand end L, as in Fig. 7, Plate 78; and we may picture to ourselves that there is a mathematical piston M between the two, an impenetrable movable mathematical surface. Begin with the molecules at absolute zero of temperature: they are then without motion, and the space dynamically occupied by them is nil. Let energy now be communicated to the molecules: the gas assumes a dynamic volume, and the ether is compressed. (The author is here departing from the rationale of this action as given in his 1880 paper; he is regarding the ether now as not bodily displaced, but only compressed in the cylinder.) Whatever be the modified velocity of the inner ethids, this is exchanged in impact for the velocity of the external ethids at the inner surface of the cylinder; and the modified velocity passes on at lightning speed into free space. The velocity of the inner ethids is therefore maintained at the normal velocity of the external ethids, in any state of compression of play-spaces; that is, the play-spaces are compressed with constant energy, and therefore with the $p\,v$ constant for each ethid. The mathematical piston will have moved from R to M during the compression, and the indicator curve of compression will be that for constant $p\,v$, that is, a common hyperbola.

Pressure of Gas.—The $p\,v$ of the ethids, which is now $p_3\,v_3$ in Fig. 7, is in amount the same as before, namely $p_1\,v_1$. The total p is increased by what is now the $p\,v$ of the gas molecules, namely $p_3\,v_2$. If we did not know that the ether is there, we should think that this $p_3\,v_2$ is the only $p\,v$ in the cylinder, and should write it as $p_2\,v_1$. The p_2 is the apparent pressure, or the excess above the external pressure.

Specific Heat at Constant Volume.—Now what is the amount of constitutional energy required by the gas molecules to bring them from zero temperature to their condition $p_3\ v_2$? The actual or motion energy of the molecules is $\frac{3}{2}\ p_3\ v_2$; and the work of compression is, say $\left(p_1 + \frac{p_2}{2}\right)\ v_2$. As p_2 is insensibly minute in comparison with p_1, it will lead to only an insensibly minute error if this work of compression be regarded as equal to $p_3\ v_2$. The sum of these—actual energy and compressive energy—is therefore $\frac{5}{2}\ p_3\ v_2$. Now although this process has been described as one of change of volume, it has really been all accomplished in a cylinder at constant volume, the ethids and the molecules being uniformly distributed and interspersed. This sum is therefore the energy required for increase of temperature at constant volume; or, for the increase of $p\ v$ by itself under any condition, the energy required is $2\frac{1}{2}$ times the increase of $p\ v$.

Specific Heat at Constant Pressure.—When the volume of gas is increased at constant pressure, there must be external work done equal to the increase of $p\ v$. In that case the statement of energy is as follows:—

Increase of motion energy	$= 1\frac{1}{2}$	times the increase of $p\ v$.		
Increase of molecular play-space	$= 1$	,,	,,	,,
External work	$= 1$	,,	,,	,,
Total energy of increase	$= 3\frac{1}{2}$	,,	,,	,,

Ratio of the two Specific Heats.—The ratio of energy required for increase of $p\ v$ at constant pressure to that required for increase of $p\ v$ at constant volume is therefore $3\frac{1}{2} \div 2\frac{1}{2} = 1 \cdot 4$. This is the number which is generally denoted by the Greek letter γ in English works on thermodynamics; it is generally given as $\gamma = 1 \cdot 408$. The latter figure is that obtained from certain experiments on the velocity of sound in air, for which the formula $U^2 = g\ \gamma\ v\ p$ should hold, where U is the velocity of sound in air in feet per second, v the volume of one pound of air in cubic feet, and p the pressure in pounds per square foot. More recent experiments give $1 \cdot 402$, a remarkably close agreement of experimental results with the preceding theoretical deduction. In a paper on Regnault's

Determination of the Specific Heat of Steam, read before the Physical Society on 25 February 1882, the author has shown that the specific heat of steam at constant pressure, required for this theoretical ratio 1·4, is also fairly corroborated by Regnault's experiments on steam. (See following Paper, pages 408–411.)

The three deductions thus arrived at may be stated as follows:—(1) in any change of molecular aggregation of matter, as from liquid to vapour or gas, the splitting heat or energy of segregation is a constant quantity at all temperatures, if the change of aggregation is the same; (2) the specific heat of gas at constant volume is $2\frac{1}{2}$ times its change of $p\,v$; (3) the specific heat at constant pressure is $3\frac{1}{2}$ times its change of $p\,v$. The word heat is here used as interchangeable with the word energy; it is convenient to do so in such a paper as this. When the unit of volume is taken to be as many of the ordinary units of volume as are expressed by the number denoting the mechanical equivalent of heat, energy and heat are expressed by the same numbers; and the number known as Joule's equivalent, elsewhere generally repeating itself in the formulæ, disappears altogether. According to this convention, which will here be followed, unit $p\,v$ is the mechanical equivalent of the unit of heat.

Second Law of Thermodynamics. — The Second Law of Thermodynamics is that, on a theta-phi diagram (page 413), for every point there is a characteristic state. The work done over any closed graph is therefore that represented by the area enclosed within it. If the enclosed area in Fig. 8, Plate 78, be divided up into elements or vertical bands by the dotted straight lines extending to the base line, it will be seen that the work area of any element is the area between the higher and lower temperatures denoted by the graph, and the heat expended on the element is the whole height of the band from the base line up to the higher temperature, and the heat thrown away is the height of the band from the base line up to the lower temperature; therefore the work efficiency of that element is the fraction which the difference of the two heights

is of the whole height of the band, that is, the fraction which the difference of the two temperatures is of the higher temperature. This fraction is what is known as Carnot's function.

It was while engaged in writing a series of papers on "Safety Valves and Steam in Motion," in *The Nautical Magazine* in 1871, that the author's thoughts became first directed to the ether-pressure theory. He discontinued the papers, as he then believed for only a month or two, until he could work out the problem. It has taken all his private time from that date until now. His object all along has been the simplification of thermodynamics for engineers. Those who care only for results, and have no desire to pry into the occult arrangements in nature whereby the results are produced, may, if they choose, ignore ether-pressure altogether, and the simplification now obtained will still hold good for their use. The only statement they need accept is that the heat of segregation is somehow a constant at all temperatures, and that the 1·4 ratio of the two specific heats of air or gas is merely a deduction from experiments: they can even refrain from putting the question, where does the latent heat hide. The author has thought it best however to write this paper from his own standpoint, and has therefore not hesitated to present some very startling statements about the universe we live in—statements which he thinks are well calculated to provoke profitable thinking, rising far above and extending far beyond the question of steam-engine economy, in which they have had their origin.

APPENDIX.

The following extracts from vol. iv of Newton's works (Horsley's edition, 1782) show how the conception of a gravitational ether originated with him, and in what state he left the theory.

28 February 1678–9. Sir Isaac Newton to the Hon. Mr. Boyle (page 394). "* * * I shall set down one conjecture more, which came into my mind now as I was writing this letter: it is about the cause of gravity. For this end, I will suppose ether to consist of parts differing from one another in subtilty by indefinite degrees: that in the pores of bodies there is less of the grosser ether, in proportion to the finer, than in open spaces; and consequently that in the great body of the earth there is much less of the grosser ether, in proportion to the finer, than in the regions of the air: and that yet the grosser ether in the air affects the upper regions of the earth, and the finer ether in the earth the lower regions of the air, in such a manner that, from the top of the air to the surface of the earth, and again from the surface of the earth to the centre thereof, the ether is insensibly finer and finer. Imagine now any body suspended in the air, or lying on the earth; and the ether being, by the hypothesis, grosser in the pores which are in the upper parts of the body, than in those which are in the lower parts; and that grosser ether, being less apt to be lodged in these pores than the finer ether below, it will endeavour to get out, and give way to the finer ether below, which cannot be, without the body's descending to make room above for it to go out into.

From this supposed gradual subtilty of the parts of the ether, some things above might be further illustrated, and made more intelligible; but by what has been said, you will easily discern whether in these conjectures there be any degree of probability; which is all I aim at. For my own part, I have so little fancy to things of this nature, that, had not your encouragement moved me to it, I should never, I think, have thus far set pen to paper about them. What is amiss therefore I hope you will the more easily pardon in yours," &c.

17 January 1692–3. Newton to Dr. Bentley (page 437). "* * * You sometimes speak of gravity as essential and inherent to matter. Pray do not ascribe that notion to me; for the cause of gravity is what I do not pretend to know, and therefore would take more time to consider of it."

25 February 1692–3. Newton to Dr. Bentley (page 438). "* * * The last clause of the second position I like very well. It is inconceivable that inanimate brute matter should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact; as it must do, if gravitation, in the sense of Epicurus, be essential and inherent in it. And this is one reason why I desired you would not ascribe innate gravity to me. That gravity should be innate, inherent, and essential to matter, so that one body may act upon another at a distance through a *vacuum*, without the mediation of anything else, by and through which their action and force may be conveyed from one to another, is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it. Gravity must be caused by an agent acting constantly according to certain laws; but whether this agent be material or immaterial, I have left to the consideration of my readers."

16 July 1717. Advertisement II (page 3). "In this second edition of these Opticks I have omitted the Mathematical Tracts published at the end of the former edition, as not belonging to the subject. And at the end of the third book I have added some questions. And to show that I do not take gravity for an essential property of bodies, I have added one question concerning its cause, choosing to propose it by way of a question, because I am not yet satisfied about it for want of experiments. I. N."

Question 21 (page 224): referring to the ether. "Is not this medium much rarer within the dense bodies of the sun, stars, planets, and comets, than in the empty celestial spaces between them? And in passing from them to great distances, doth it not grow denser and denser perpetually; and thereby cause the gravity of those great bodies towards one another, and of their parts towards the bodies; every body endeavouring to go from the denser parts of the medium towards the rarer? For if this medium be rarer within the sun's body than at its surface, and rarer there than at the hundredth

part of an inch from its body, and rarer there than at the fiftieth part of an inch from its body, and rarer there than at the orb of Saturn; I see no reason why the increase of density should stop anywhere, and not rather be continued through all distances from the sun to Saturn, and beyond. And though this increase of density may at great distances be exceeding slow, yet, if the elastic force of this medium be exceeding great, it may suffice to impel bodies from the denser parts of the medium towards the rarer, with all the power which we call gravity. And that the elastic force of this medium is exceeding great may be gathered from the swiftness of its vibrations. Sounds move about 1,140 English feet in a second minute of time; and in seven or eight minutes of time they move about one hundred English miles. Light moves from the sun to us in about seven or eight minutes of time; which distance is about 70,000,000 English miles, supposing the horizontal parallax of the sun to be about 12″. And the vibrations or pulses of this medium, that they may cause the alternate fits of easy transition and easy reflexion, must be swifter than light; and by consequence above 700,000 times swifter than sounds. And therefore the elastic force of this medium, in proportion to its density, must be above 700,000 × 700,000 (that is, above 490,000,000,000) times greater than the elastic force of the air is in proportion to its density. For the velocities of the pulses of elastic mediums are in a sub-duplicate ratio of the elasticities and the rarities of the mediums taken together."

Question 28 (page 237). "*** And for rejecting such a medium," a dense fluid, "we have the authority of those the oldest and most celebrated philosophers of Greece and Phœnicia, who made a *vacuum* and atoms, and the gravity of atoms, the first principles of their philosophy; tacitly attributing gravity to some other cause than dense matter. Later philosophers banish the consideration of such a cause out of natural philosophy, feigning hypotheses for explaining all things mechanically, and referring other causes to metaphysics. Whereas the main business of natural philosophy is to argue from phenomena without feigning hypotheses, and to deduce causes from effects till we come to the very first cause; which

certainly is not mechanical: and not only to unfold the mechanism of the world, but chiefly to resolve these and such like questions. What is there in places empty of matter? and whence is it that the sun and planets gravitate towards one another, without matter between them? *** "

In Question 31 (page 242). "For it is well known that bodies act upon one another by the attractions of gravity, magnetism, and electricity; and these instances show the tenor and course of nature, and make it not improbable but that there may be more attractive powers than these. For nature is very consonant and conformable to herself. How these attractions may be performed, I do not here consider. What I call attraction may be performed by impulse, or by some other means unknown to me. I use that word here to signify only in general any force by which bodies tend towards one another, whatsoever be the cause. For we must learn, from the phenomena of nature, what bodies attract one another, and what are the laws and properties of the attraction, before we enquire the cause by which the attraction is performed."

In Question 31 (page 261). "To tell us that every species of things is endowed with an occult specific quality, by which it acts and produces manifest effects, is to tell us nothing: but to derive two or three general principles of motion from phenomena, and afterwards to tell us how the properties and actions of all corporeal things follow from those manifest principles, would be a very great step in philosophy, though the causes of those principles were not yet discovered: and therefore I scruple not to propose the principles of motion above mentioned, they being of very general extent, and leave their causes to be found out."

THE RATIONALIZATION OF REGNAULT'S EXPERIMENTS ON STEAM.

By Mr. J. MACFARLANE GRAY, of London.

In a paper* read before the Institution of Naval Architects on 11th April of the present year, the author has endeavoured to deduce the two following thermodynamical principles (page 393) from Newton's cosmical hypothesis of a corpuscular gravitational ether:—

1. In any change of molecular aggregation of matter, as from liquid to vapour or gas, the splitting heat or energy of segregation is a constant quantity at all temperatures, if the change of aggregation is the same.

2. The heat or energy communicated to a gas, to change its pv product (pressure × volume) by any small amount, is for constant volume $2\frac{1}{2}$ times its change of pv, and for constant pressure $3\frac{1}{2}$ times its change of pv.

The Rationalization which he now offers of the results obtained in Regnault's Experiments on Steam consists in demonstrating how the inter-relation of these results can be deduced from the above principles and from the Second Law of thermodynamics, without the assumption of any arbitrary constants.

For the purpose of the present paper it will not be necessary to refer again to the ether-pressure theory.* The two principles already enunciated are themselves sufficiently fundamental to make the investigation interesting; and to go deeper would require more time than can be given to this paper at the present meeting. The author remembers having been shown during the first Paris Meeting of this Institution in 1867 the apparatus used by Regnault, then preserved in the Conservatoire des Arts et Métiers;† and it is as a tribute of respect to Regnault that he has proposed to read this paper in Paris, where those immortal experiments were carried out and so generously given to all nations.

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* See preceding page 379. † See page 404, and also discussion, pages 452–453.

The meanings of certain terms employed in the paper are slightly different from those commonly given to them; these will be explained as they are introduced.

Heat, as a phenomenon, is the sensible aspect of molecular motion.

Heat, as a quantity, is the constitutional energy of molecular motion expressed in terms of a standard unit.

p = pressure in any unit.

v = volume in such a unit that the unit of the pv product (pressure $\times$ volume) denotes the thermodynamic unit both of heat and of energy.

θ = absolute temperature centigrade, the temperature of melting ice being $\theta_0 = 273°$ centigrade absolute. Throughout the paper absolute temperature will be adhered to, unless when quoting from Regnault.

t = temperature centigrade according to the common scale, which starts from the melting point of ice as zero.

Centigrade scale and *common* logarithms will alone be employed in this paper.

Unit of Heat is that quantity of constitutional molecular energy which is mechanically equivalent to the variation of the pv product for the unit mass of hydrogen gas per degree, at the temperature of melting ice and atmospheric pressure: that is, 1,386 foot-pounds for the centigrade degree and pound mass, or 770 foot-pounds for the Fahrenheit degree and pound mass; for the centigrade degree and kilogram mass, the mechanical equivalent of this unit of heat is 422·449 kilogram-mètres. In Regnault's calculations he employed as unit the amount of heat that raises one kilogram of water one degree centigrade at about the temperature of 15° centigrade; his unit is 1·0106 times the unit of heat now defined (page 405).

Unit of Energy in thermodynamics is in this paper, for arithmetical convenience, taken to be the same as the mechanical equivalent of the unit of heat as given above.

The water unit of heat which has hitherto been the standard adopted is most unsuitable. The specific heat of water is not known with accuracy at the standard temperature; and even if

it were, it would not, for any known reason, be arithmetically commensurable with any other definite physical quantity. Hydrogen is an elementary substance, and its atomic weight is the standard unit in the arithmetic of chemistry. The specific pv of hydrogen gas is on this account most appropriate for the standard unit of heat and of energy in the arithmetic of thermodynamics. Fortunately the unit now proposed is not sensibly different from the unit hitherto in use. Substantially therefore the unit remains about the same as before, and only the definition is altered.

Specific Heat of Water.—The report of Regnault's experiments on the specific heat of water is the last in his first volume. The columns of data do not agree with the column of results. The author drew attention to this in a letter to *Engineering*, 9th January 1885. In the new edition of Wüllner's *Experimental-physik*, published also in 1885, the author's recalculations are independently corroborated. Wüllner accepts the data columns as correct, and from the recalculation concludes that the specific heat of water may be taken to be constant up to 190°. The author thinks that the apparent discrepancy is due to a wrong statement of the weights of the hot water, and that Regnault calculated his results from the correct weights. In the following formula on page 739 of his report is stated the manner in which the calculation is to be made, when a small quantity π of cold water is poured back again into the calorimeter: $(P_1 - P_0 + p - \pi)\, x\, (T - t_1) = (P_0 - p - \pi)(t_1 - t_0)$. Now the negative sign of π in the second half of this equation is a misprint not given in any of the lists of errata; it ought to be $+\pi$. As printed it gives the weight of cold water, $P_0 - p - \pi$, too small. The author thinks that this too small weight has been deducted from P_1, instead of taking the correct quantity $P_1 - P_0 + p - \pi$ for the weight of hot water; and that this mistake has been made after the column of results had been calculated from the correct weights. The sum of the weights of the hot and the cold water, in every one of the experiments which are thought to be mis-stated, seems to be greater than the capacity of the calorimeter, and in each of these the weight of hot water is notably excessive,

TABLE 1.—*Specific Heat of Water, revision.*

No. of Experiment.	A	B	C	D	E	F	G	H	$t°$
	Weight of Cold Water. Regnault.	Weight of Hot Water. Regnault.	Total Weight of Water, A+B.	Calorimeter Capacity up to zero line.	C−D	Mean Specific Heat of Water, 0° to $t°$. Regnault's results.	Recalculated from data.	Difference of F and G.	Temperature centigrade.
No.	Grammes.	Grammes.	Grammes.	Grammes.	Grammes.				°
1	99626·6	10059·8	109686·4	109644·2	42·2	1·00184	1·00208	0·00024	107·70
2	99656·0	10035·6	109691·6	109642·3	49·3	1·00440	1·00441	0·00001	107·90
3	99614·4	10187·0	109801·4	109632·2	169·2	1·00527	0·99261	0·01266	107·79
4	99672·6	10057·4	109730·0	109693·6	36·4	1·00476	1·00475	0·00001	109·38
5	99692·7	10038·3	109731·0	109695·1	35·9	1·00837	1·00840	0·00003	109·25
6	99664·8	10064·8	109729·6	109691·4	38·2	1·00687	1·00689	0·00002	109·25
7	99657·6	10075·9	109733·5	109692·7	40·8	1·00659	1·00661	0·00002	109·25
8	99642·3	9995·9	109638·2	109600·8	37·4	1·00540	1·00518	0·00022	110·80
9	99618·3	9999·6	109617·9	109597·2	20·7	1·00489	1·00502	0·00013	111·51
10	99583·6	10039·6	109623·2	109586·3	36·9	1·00552	1·00501	0·00051	113·86
11	99640·7	10180·0	109820·7	109613·8	206·9	1·00791	0·99055	0·01736	116·60
12	99638·6	10182·0	109820·6	109614·7	205·9	1·00741	0·99053	0·01688	116·91
13	99635·8	10192·0	109827·8	109613·5	214·3	1·00599	0·98681	0·01918	118·54
14	99626·0	9973·0	109599·0	109579·8	19·2	1·00499	1·00534	0·00035	120·39
15	99568·4	10036·4	109604·8	109575·0	29·8	1·00443	1·00477	0·00034	120·84
16	99628·6	9966·4	109595·0	109576·6	18·4	1·00681	1·00735	0·00054	121·86

17	99628·6	9979·6	109608·2	109581·5	26·7	1·00631	1·00635	0·00004	128·91
18	99658·6	9959·4	109618·0	109581·6	36·4	1·00568	1·00654	0·00086	130·40
19	99631·6	9957·8	109589·4	109557·7	31·7	1·00738	1·00807	0·00069	137·16
20	99635·7	9949·1	109584·8	109556·9	27·9	1·00786	1·00921	0·00135	137·27
21	99641·6	9929·6	109571·2	109556·3	14·9	1·00663	1·00773	0·00110	138·27
22	99650·1	9886·5	109536·6	109506·5	30·1	1·00724	1·00760	0·00036	153·68
23	99642·6	9904·4	109547·0	109522·7	24·3	1·00848	1·00881	0·00033	154·80
24	99635·0	9928·2	109563·2	109520·5	42·7	1·00642	1·00672	0·00030	155·61
25	99652·2	9887·8	109540·0	109513·8	26·2	1·00925	1·00940	0·00015	156·82
26	99626·4	9912·2	109538·6	109507·8	30·8	1·00780	1·00824	0·00044	158·82
27	99662·5	10150·0	109812·5	109516·2	296·3	1·00699	0·98296	0·02403	159·19
28	99643·6	9886·6	109530·2	109504·3	25·9	1·00952	1·00973	0·00021	160·34
29	99742·6	10011·0	109753·6	109518·1	235·5	1·01053	0·99021	0·02032	160·61
30	99686·2	9931·2	109617·4	109576·1	41·3	1·00923	1·00956	0·00033	172·66
31	99689·8	9925·2	109615·0	109570·6	44·4	1·01201	1·01232	0·00031	172·75
32	99696·6	9915·6	109612·2	109568·8	43·4	1·01207	1·01237	0·00030	172·71
33	99676·0	9947·6	109623·6	109565·8	57·8	1·01228	1·01259	0·00031	172·66
34	99786·3	10125·0	109911·3	109463·5	447·8	1·01662	0·97975	0·03687	179·23
35	99774·8	10102·0	109876·8	109459·0	417·8	1·01430	0·97482	0·03948	183·55
36	99784·8	10105·0	109889·8	109449·2	440·6	1·01499	0·97494	0·04005	186·00
37	99687·4	10152·0	109839·4	109443·0	396·4	1·01756	0·97978	0·03778	186·65
38	99646·6	10182·0	109828·6	109440·2	388·4	1·01487	0·98040	0·03447	186·89
39	99710·8	10160·0	109870·8	109425·4	415·4	1·01621	0·97574	0·04047	187·75
40	90713·0	10107·0	109820·0	109422·4	397·6	1·01528	0·97990	0·03538	190·36

abruptly differing from the adjacent quantities. The heading of one of the columns is printed "Température *initiale* du calorimètre" instead of "*finale;*" all tending to prove that the report was hurried at the last in order to get it into the first volume. In the accompanying Table 1, columns A, B, and F, are from Regnault's Table, and the others have been calculated by the author to account for the discrepancies between columns F and G.

In column D is given the capacity of the calorimeter up to the zero line on the glass gauge tube, according to the final temperature and the Table given by Regnault on his page 735. The excess for each experiment, given in column E, must be the weight of water, in grammes, above the zero mark in the gauge tube. Where Regnault's results and the recalculations agree, the quantity in column E is always small. When these do not agree, the quantity in column E is very great. In experiment No. 34 for example there was, according to column E, 447·8 grammes of water in the gauge glass; while, according to the drawing given of the apparatus, the gauge glass could not contain that quantity even if full. As the stirring rod passed through it, its available capacity would be thereby reduced; and also, to prevent loss of water when stirring, it would not be filled nearly full. These figures are stated here, as there may be an opportunity when the paper is read of verifying the conclusions arrived at, by examination of the actual apparatus now preserved in the laboratory of the Collége de France. (See discussion, pages 452–455.)

More recent experiments, especially those made in 1883 by Rowland at Baltimore, U.S., show that the specific heat of water is not constant at the low temperatures which were taken as unity in Regnault's calorimetric experiments. The specific heat diminishes one per cent. between 5° C. and 29° C., and from the latter temperature it increases. Rowland's experiments extend only to 36° C. The most important determination of heat quantity by Regnault is that for the total heat of steam at 100° C. Six of the experiments were preliminary trials. For the remaining thirty-eight experiments the mean calorimetric temperature was 15° with a range of 13°. Over this range the mean of Rowland's specific heats is that which is

equivalent to lifting the unit of weight 427·445 mètres. Deducting 0·5 on account of the difference of latitude, in order to reduce to $g = 32 \cdot 2$, gives 426·945 mètres. The unit of heat adopted in this paper corresponds to 1,386 feet lift or 422·449 mètres, therefore $426 \cdot 945 \div 422 \cdot 449 = 1 \cdot 0106$, which is the specific heat of aquene or ideal water to be employed in this paper, constant at all temperatures at which water can exist as a liquid. As Regnault considered the specific heat of water to be unity for the above calorimetric temperatures, Regnault's unit of heat is 1·0106 times the unit adopted in this paper.

Aquene is an ideal substance; it is water regarded as having a bulk equal to only the absolute matter-volume of its molecules. The constant specific heat adopted in this paper is therefore less than the specific heat of water.

The heat Q required to raise the temperature of water to θ degrees absolute from 273° absolute, at which the pv of water is so small a quantity that it may be neglected, is in this paper regarded as being

$$Q = 1 \cdot 0106\,(\theta - 273) + \theta\, v \frac{dp}{d\theta}$$

where v is the actual volume of unit mass of water at temperature θ, less its absolute matter-volume, the pressure during the heating being that due to the higher temperature. Absolute matter is no doubt much more dense than platinum; and the reduction from the apparent volume, being very small, may therefore be disregarded in the following comparison.

The pv of unit mass of water is $= \frac{pw}{c}$ thermal units. Here $w =$ relative volume of water, the volume at maximum density being regarded as $=$ unity; and $c =$ a constant divisor. This divisor $c =$ 601, when p is in pounds per square inch; $c = 31{,}071$, when p is in millimètres of mercury; $c = 422{,}449$, when p is in kilograms per square mètre. Employing for $\frac{dp}{d\theta}$ the values given in the tables in "Principes de Thermodynamique," by Paul de Saint-Robert, the divisor is 422,449. The mean specific heat between $t°$ and the temperature of melting ice, compared with that at $t = 4°$, is, according to the Second Law as to be set forth in this paper,

$$1 + \frac{w}{1 \cdot 0106 \times 422{,}449} \; \frac{\theta}{t} \; \frac{dp}{d\theta}.$$

According to this formula, and taking the values of the factor w from Hirn's experiments, the following Table 2 is calculated for the specific heat of water.

TABLE 2.

Mean Specific Heat of Water,
for the interval between $t°$ and the temperature of melting ice, expressed in Regnault's units.

$t°$	$\theta°$	w	$\frac{dp}{d\theta}$	Mean Specific Heat.
100	373	1·04315	370	1·00337
120	393	1·05992	564	1·00458
140	413	1·07949	1048	1·00782
160	433	1·10149	1611	1·01125
180	453	1·12678	2358	1·01566
200	473	1·15900	3310	1·02125

To compare the results given by Regnault in column F, Table 1, with the last column of the above Table 2, it has to be observed that the former have to be reduced a little for the difference of range, the mean in Table 2 being down to $t = 0°$, while in Table 1 it is only down to the final temperature of the calorimeter, say 21°. The results in Table 2 have also to be reduced for the absolute matter-volume. Having regard to the extreme difficulty of these experiments, and the consequent irregularity of some of the results, the author thinks that the column of mean specific heat in Table 2, calculated quite independently, substantially corroborates Regnault's column F in Table 1. This rationalization of experimental results will be better understood when the theta-phi diagram is explained. The important deductions in this paper are independent of the varying specific heat of water.

Ratio of the two Specific Heats.—The ratio of the specific heat of a gas at constant pressure to the specific heat of the same gas at constant volume is generally represented by the Greek letter γ, with a numerical value 1·408, 1·414, 1·402; or, as in this paper, 1·4. The generally adopted value 1·408 is that obtained from experiments on the velocity of sound in air, for which the equation $U^2 = g\,\gamma\,v\,p$ ought to hold. Here U = velocity of sound in air in units of length per unit of time, g = accelerity * of gravitation at a standard place,

* Accelerity is the rate at which acceleration is acquired.

v = volume of unit mass of air, p = pressure: all being in the same system of units. According to the velocity of sound in air as determined by

Regnault, .	330·7	mètres per second,			$\gamma = 1·3953$
Moll and Beck,	332·26	,,	,,	,,	$\gamma = 1·4085$
Szathmari, .	331·57	,,	,,	,,	$\gamma = 1·4027$

From the ether-pressure theory (page 392) the author obtains $\gamma = 3\frac{1}{2} \div 2\frac{1}{2} = 1·4$. Szathmari's experiments were made in 1878, and the velocity obtained is the mean of thirty experiments, all agreeing very closely. This practical result is thought to be a sufficiently close corroboration of the author's theoretical deduction. The γ ratio with a value near to 1·4 has long been accepted as an established physical relation applying to the specific heats of the permanent gases; but according to Regnault's report it does not apply to steam gas. Inasmuch as for permanent gases the pv product for unit mass at any one temperature is inversely as the molecular weight of the substance, the 1·4 ratio is an important physical relation. According to the kinetic theory, pv is proportional to the motion energy of the mass of molecules, while temperature θ is proportional to the motion energy per active molecule. At the same temperature therefore, the greater the number of molecules, the greater the energy. Since the number of molecules in unit mass must be inversely as the molecular weight, we get pv inversely proportional to the molecular weight, at any one temperature. For what has generally been called perfect gas, the ratio 1·4 gives, in the notation adopted in this paper,

$$\text{Specific } pv = \frac{2}{m}$$

$$\text{Specific heat at constant volume} = \frac{5}{m}$$

$$\text{Specific heat at constant pressure} = \frac{7}{m}$$

where m stands for the molecular weight of the substance. Further on it will be shown that saturated steam is perfect gas in the sense of being matter completely gasified, and therefore consisting of matter travelling in single molecules. The purely ideal state for which the pv product is strictly proportional to the temperature will

be called *gasene* in this paper; it is what has hitherto been called perfect gas. The term *vapene* will be employed to denote gasene of maximum pressure at any temperature.

It would be an important simplification if it could be established that the ratio 1·4 applies also to steam and other gases. In this paper the author will deal with steam only. It has long been known that the relation $\frac{2}{m}\theta = pv$ holds good for steam at low temperatures where it is assumed to be almost in the gasene state. For steam the specific heat at constant pressure would require to be $\frac{7}{m} = 0 \cdot 38976$; and Regnault's report makes the specific heat of superheated steam at atmospheric pressure 0·4805. In a paper read before the Physical Society on 25 February 1882 the author has pointed out what seems to him to be an oversight in that report, whereby the specific heat has been misrepresented; and when this is put right, the ratio 1·4 is corroborated for steam. In the experiments reported by Regnault, steam of atmospheric pressure was superheated at the same pressure up to 124° C. The heat abandoned in the calorimeter from that temperature down to 0° C. was ascertained by experiment. Steam was then superheated to 224° C. under the same pressure, and the heat abandoned was ascertained as before. The difference was found to be 48·05 units; the difference of temperatures was 100°; therefore the mean specific heat for that change of temperature was reported by Regnault as 0·4805. This was Regnault's method, and it seems at first glance to be all right. The first stage of superheating was probably undertaken in order to make sure that at the lower temperature the steam should be quite free from moisture, so that only the heat of change of temperature should be taken into account, and that the result should not be vitiated by including in the heat abandoned any portion of the heat required for evaporation. If this ground of procedure were correct, then if similar experiments were made between the temperatures 100° C. and 124° C., the resulting specific heat would come out much greater than that obtained by Regnault. The author however thought that any particles of moisture in the steam at 100° C. would not be evaporated up to 124° C.; but they would be more likely to be evaporated in the

higher range of temperature. This surmise could be easily put to the test; and indeed we can actually get the test carried out by Regnault himself, who in his first volume, pages 694–8, has reported thirty-eight careful experiments on the "total heat" of steam at atmospheric pressure, the mean result being 636·68 units of heat.

In the following Table 3 the author has re-stated on this plan all the sixteen experiments in which Regnault used the large

TABLE 3.—*Specific Heat of Steam at atmospheric pressure.*

A Superheated.	B "Total heat."	C B − 636·68	D C ÷ A
Degrees Cent.	Units.	Units.	Specific Heat.
24·32	643·96	7·28	0·2993
23·11	643·95	7·27	0·3145
21·71	644·07	7·39	0·3404
28·11	647·25	10·57	0·3760
27·08	647·54	10·86	0·4011
18·71	644·39	7·71	0·4120
22·47	644·55	7·87	0·3503
26·84	647·78	11·10	0·4136
23·86	646·37	9·69	0·4061
26·86	647·84	11·16	0·4155
24·81	646·28	9·60	0·3869
20·34	644·44	7·76	0·3815
23·14	644·70	8·02	0·3466
24·25	644·20	7·52	0·3101
20·53	645·47	8·79	0·4282
23·43	647·54	10·86	0·4635
Mean specific heat			0·3778

calorimeter, pages 176–7, vol. 2. In column A is given the number of degrees centigrade through which the steam was superheated at atmospheric pressure. Column B gives the recorded "total heat" in Regnault's units from the temperature of melting ice. Column C

gives the excess of that total heat, above the 636·68 units of total heat from water at the temperature of melting ice to steam at atmospheric pressure. Column D gives the apparent mean specific heat through the low range of superheating, all in Regnault's units. The mean is 0·3778, which multiplied by 1·0106 gives the mean specific heat in these sixteen experiments to be 0·3818 in the units employed in this paper. The specific heat of saturated steam at atmospheric pressure, according to the theory worked out in this paper, is 0·3830; and the specific heat when the steam is slightly superheated is a minute fraction greater than 0·3830. The mean of Regnault's experiments may therefore be said to corroborate the theoretical expectation accurately; but such very close agreement is only a statistical mean, as is seen by the range of variation exhibited in the results given in column D. The nearness of Regnault's results to the deductions of a theory unknown to him shows, if the theory is accepted, that his experiments were most carefully conducted, and that the inevitable errors of observation have had no preponderance.

Heat of Evaporation.—According to the theory now being applied to steam, the heat of evaporation consists of the splitting heat or energy of segregation, which is a constant at all temperatures, and the constitutional energy of the gas state, namely $\frac{7}{2}pv$. It will be borne in mind that the unit of pv is also the unit of heat, according to the convention agreed upon in this paper (page 400). The constitutional energy $\frac{7}{2}pv$ will be taken to be equal to $\frac{7}{m}x\ \theta$, where θ is the absolute temperature, and x is a variable which will afterwards be shown to be a known function of the temperature. The heat of segregation for water is 501·4 units, in addition to the heat which has already been communicated to water at the temperature of melting ice. A slight difference in the 501·4 throws the pressures out of agreement with the experimental results. It will be shown however that this value is also in agreement with Regnault's determinations of total heat or of latent heat. It gives the total heat of steam at 100° as 637·49 in Regnault's units;

and in the thirty-eight experiments already referred to, Regnault's results range from 635·6 to 638·4, with a general mean of 636·68. The difference $637{\cdot}49 - 636{\cdot}68 = 0{\cdot}81$, which is only about one-eighth of one per cent., and is a remarkable corroboration of the accuracy of Regnault's work, if the theory now presented is accepted.

The coefficient x denotes the fraction which the actual pv is of what would be the pv of the same weight of gasene at the same temperature. As this paper refers to steam only, it is always ideal steam that is meant when the term gasene is employed.

The molecular weight of hydrogen being 2, its specific pv is $\frac{2}{m} = \frac{2}{2} = 1$. The molecular weight of water is generally taken to be 18. More accurately however it is—

$$H_2O = \begin{cases} \text{Two hydrogen atoms} & = 2{\cdot}0000 \\ \text{One oxygen atom} & = 15{\cdot}9598 \end{cases}$$

$$\text{Molecular weight of water} = 17{\cdot}9598$$

and this is the value of m which is adopted for water in this paper. The slight divergence from 17·96 was adopted, not for greater accuracy although it is in that direction, but only in order to get the following numbers complete to five places of decimals for ideal steam or gasene :—

$$\text{Specific } pv \quad . \quad . \quad . \quad . \quad = \frac{2}{m} = 0{\cdot}11136$$

$$\text{Specific heat at constant volume} = \frac{5}{m} = 0{\cdot}27840$$

$$\text{Specific heat at constant pressure} = \frac{7}{m} = 0{\cdot}38976$$

The Theta-Phi ($\theta\phi$) Diagram. — The intelligent grasp of thermodynamic principles and their consequences has been greatly hindered by the abstruse mathematical method adopted by all standard authors when expounding this science. The author has been greatly assisted in his investigations by the theta-phi diagram which he has employed constantly since 1879. The energy or work diagram commonly employed in thermodynamics has *pressure* and *volume* for its rectangular co-ordinates, the area being pv or work. On that pee-vee diagram the important lines denoting temperature

and adiabaticity are curves, difficult to draw, and when drawn affording little assistance to the mind in trying to comprehend thermodynamic relations. This defect is due principally to the circumstance that the diagram does not represent the energy possessed by the working substance at any instant, but merely the work it has performed. For any special problem the new lines are difficult curves, and the permanent lines are only the rectangular axes. In the theta-phi diagram the permanent lines are the difficult curves, drawn once for all. For any special problem the new lines are all straight, and the whole energy possessed at any instant can be seen by inspection, as well as the order in which thermation or ergation proceeds, that is, the change of mechanical energy into heat or of heat into mechanical energy.

In the new diagram, shown for gasene in Fig. 10, Plate 80, and for steam in Fig. 24, Plate 86, the vertical ordinate is temperature θ, reckoned from absolute zero; the area is quantity Q of heat or energy in heat units; and the horizontal dimension is therefore made up of the quotients of every successive addition of heat divided by the temperature at which it is received or abandoned. The horizontal dimension is that for which Clausius in his purely mathematical treatise invented the name "entropy." The theta-phi diagram always refers to the thermodynamic transformation of a unit of mass of the working substance.

Entropy is therefore, in this paper, length upon a diagram whose height is absolute temperature θ and whose area is energy Q in heat units. The Greek letter ϕ was used by Rankine and by Maxwell to denote entropy, which was called by Rankine "the thermodynamic function." The Greek letter θ was used by Maxwell to stand for absolute temperature. The author has therefore given the name "theta-phi" to this heat diagram, just as "pee-vee" is a name for the common work diagram of pressure and volume. The ordinates in the new diagram are represented by Greek letters, while the ordinates in the old diagram are represented by English letters. The new diagram is sometimes called the temperature-entropy diagram. Instead of the word entropy, the word "longitude" might have been employed; because, regarding the diagram as a heat

chart, the meaning of entropy on the theta-phi diagram is precisely what is meant by longitude on a terrestrial chart. That which is called entropy and denoted by ϕ is, with the absolute temperature θ, the co-dimension or co-ordinate of energy. Force and travel, pressure and volume, temperature and entropy, are all different pairs of co-ordinates of energy. In Fig. 24, Plate 86, the figures marked along the horizontal line at 273° absolute temperature denote entropy, and the horizontal dimension of each square is one-tenth of the unit of entropy. The area of each square represents two units of heat.

Graph is the name given to any line on the diagram regarded as describing a series of thermodynamic transformations. A graph is a continuous series of state-points, or of points relative to the state-points. In the pee-vee diagram, pressure, volume, and work are represented, while heat and temperature are graphically ignored. In the theta-phi diagram, temperature, entropy, and heat are represented, and the work done may be ignored altogether in drawing any state-point graph.

Upon the theta-phi diagram the Second Law of Thermodynamics is that each point on the diagram is a characteristic state-point: that is, starting from any initial state represented by a point on the diagram, and proceeding by any series of thermodynamic transformations denoted by any graph on the diagram, when the initial point is again arrived at, the working substance will also have returned to its initial state. The area swept by the vertical ordinate in travelling to the right is heat imparted to the working substance; to the left it is heat given out by the substance. The diagram is merely the graphic representation of the Carnot-Clausius function. The validity of the diagram, as well as of the Carnot-Clausius fundamental principle or second law, depends upon the validity of a differently worded and simpler proposition, namely:—when heat is communicated to or from a body in any definite order, having regard to quantity of heat and temperature, the body simultaneously undergoes a definite thermodynamic change for which there is no alternative; and the action is reversible, and compoundable in the sense in which forces or velocities can be

compounded. This is equivalent to saying that in nature the thermodynamic conditions of any substance are localized upon a heat chart; and, just as a course stated in terms of change of latitude and difference of longitude defines a track upon the earth, so is a body represented to pass from one thermodynamic state to another by a graph upon the theta-phi diagram, the graph marking a certain change of temperature and a certain difference of entropy. The permanent curves upon the diagram are, all the time, exhibiting what are the thermodynamic properties of the substance: so that the materials we have to work upon are always clearly before us.

In Fig. 10, Plate 80, is represented the theta-phi diagram for water. Strictly the curves are the ideals for ice, aquene, vapene, and gasene. The base line ∞ Z_7 denotes absolute zero of temperature. From ∞ to 𝔄 273, the curve on the left, the substance is ice, of which the melting point is 273° centigrade absolute temperature. The specific heat of ice is assumed to be 0·5, and the successive portions of entropy ϕ, or longitude upon that curve, are therefore $\Delta\,\phi = \frac{0 \cdot 5}{\theta}\,\Delta\,\theta$. Here Δ is written as a contraction for the words "a small difference in." When the steps of difference are taken infinitely small, the equation is written $d\,\phi = \frac{0 \cdot 5}{\theta}\,d\,\theta$, the symbol d standing for the words "an infinitely small difference in." Up to any point on the curve the area between the curve and the base line out to infinity is the heat which has been received by the ice from 0° absolute up to that temperature. If θ denote the temperature, the area or heat imparted up to that temperature is $\frac{\theta}{2}$; that is, the area of the ice curve of state-points is numerically half the vertical ordinate. When the area of a curve is in this manner a constant multiple of the vertical ordinate, the curve is called logarithmic, and the horizontal dimension is the same multiple of the hyperbolic logarithm as the area is of the vertical ordinate. Like entropy and longitude, logarithms are measured from a certain arbitrary position, generally from the unit vertical ordinate, whose position is made the zero in reckoning the horizontal dimensions. Common logarithms have the vertical ordinate 2·3026 times the area. When the area is equal to the vertical ordinate, as it is in the curve for hyperbolic

logarithms, the horizontal dimension is therefore 2·3026 times what it is for common logarithms. The squarelets on the diagram represent each two units of heat.

The curve from A 273 upwards is that for the heating of water at constant volume, or really of the ideal form of water called aquene in this paper. For this the specific heat is 1·0106 (page 405); therefore the horizontal dimension is 1·0106 times the increase in the hyperbolic logarithm of the temperature. Writing $\epsilon = 2 \cdot 3026$, the horizontal dimension from the temperature θ_0 to any other temperature θ can be expressed as $1 \cdot 0106 \, \epsilon \log \frac{\theta}{\theta_0}$, using common logarithms.

The A curve, Fig. 10, Plate 80, which is the primary curve in the theta-phi diagram, is an ideal curve, the graph for aquene. The graph for actual water is W, as shown on the sketch diagram, Fig. 12. The water curve is so close to that for aquene that they cannot both be shown here on a diagram drawn to scale. In the deduction of pv from the kinetic theory the v is the dynamic volume, including the volume of the initial liquid less its absolute matter-volume. The primary curve from which the constant splitting heat is set off is therefore the graph for aquene. The heat represented by the area $A_{273} \; A_\theta \; W_\theta$ is not communicated to the liquid when it is heated under increasing pressure. Let Fig. 11 be a pee-vee sketch diagram, on which

$a\,f$ = pressure at temperature θ_1.
$a\,b$ = absolute matter-volume at θ_0.
$a\,c$ = liquid volume at θ_0.
$f\,k$ = liquid volume at θ_1.

The pressure at θ_0 is here regarded as nil. The external work of the expanding water is $c\,k\,e$, the vertical bands may be regarded as the elements $p \frac{dv}{d\theta} d\theta$. The area of $f\;k\;c\;a$ is the sum of all the elements $V \frac{dp}{d\theta} d\theta$, in which V denotes the varying water volume. If we write v for the volume less the absolute matter-volume, which is the reading of v throughout this paper, the area $g\;k\;c\;b$ will then be the sum of the elements $v \frac{dp}{d\theta} d\theta$. It is the area of $g\;k\;c\;b$ which is equal to the area between the A curve and the W curve in Fig. 12. The latent heat of evaporation is measured from W, but in the

thermodynamic relations referred to in this paper, $S + \frac{7}{2} pv$ extends to the A curve, S representing the splitting heat or energy of segregation. The whole area between the two curves, up to the highest temperature in Regnault's experiments, is less than half a unit of heat. In the theta-phi diagrams the A curve only will be drawn, representing aquene.

Between 𝔄 273 and A 273, Fig. 10, Plate 80, the state-point advances along a horizontal line whose length is 0·296; so that the area swept by the vertical ordinate in the interval is 80·8 units of heat, which is the heat of liquefaction of ice to water. At 𝔄 273 the state-point represents the unit weight of ice. Midway between 𝔄 273 and A 273 the point represents half-a-pound of water and half-a-pound of ice. At A 273 the point represents one pound of water. Making A 273 the zero of entropy, the heat of segregation for water, measured to the right from the ordinate at A 273, is 501·4 units of heat, which is the area of the rectangle A 273, B 273, Z_5, Z_0. The curve B is drawn so that this is also the area from the A 273 ordinate up to any pair of co-ordinates intersecting at one point the curve B; that is, the area bounded by the A curve, the θ temperature line to B, and the vertical from B θ, is a constant, representing the heat of segregation. Denoting by AB the horizontal distance from the A curve to the B curve at any temperature under consideration, we have the following simple geometrical property of the B curve: its subtangent on the base line is always equal to AB at the temperature for which the tangent is drawn; consequently its subtangent on the vertical through the A point is equal to θ. Because, if the area is constant and the A curve fixed, $\mathrm{AB}\ d\theta = -\ \mathrm{BZ}\ d\phi = -\ \theta\ d\phi$; therefore $\mathrm{AB} = -\ \theta \frac{d\phi}{d\theta}$ = subtangent on base; and therefore $-\ \mathrm{AB} \frac{d\theta}{d\phi} = \theta$ = subtangent on vertical through the A point.

In addition to the splitting heat or energy of segregation, there is also the constitutional heat or energy of the gas state $= \frac{7}{m} = 0·38976$ per degree of temperature. If the G curve be the same as the B curve, but merely shifted by this amount 0·38976 to the right of B, the heat imparted when the state-point comes to G

at any temperature will have been the heat of segregation up to B, and in addition $\frac{7}{m}\,\theta$ up to G. The G curve is therefore that of the state-points of gasene at maximum pressure or of saturated gasene, which is here called vapene (page 408).

Why steam should have a certain maximum pressure for each temperature can now be explained. The specific heat of gasene at constant pressure is $\frac{7}{m}$. If at G 273 the pressure is p_o, the graph P can be drawn for increase of temperature at constant pressure p_o. The required graph must be a portion of that logarithmic curve whose area is $\frac{7}{m}\,\theta$. The horizontal travel on the graph, from $\theta_0 = 273°$ to θ, will therefore be $\frac{7}{m}\,\epsilon\,(\log\theta - \log\theta_0) = \frac{7}{m}\,\epsilon\log\frac{\theta}{\theta_0}$. Now when gasene is compressed at constant temperature θ, all the work of compression is thermated, that is, changed into heat. The graph for this action will be the horizontal line at temperature θ, and the vertical ordinate will sweep an area equal to the thermation accompanying the action. It is well known in elementary thermodynamics that the area of an isothermal compression curve from $p_0\,v_0$ to $p\,v$ is $p\,v\,\epsilon\log\frac{p}{p_0}$. Now for gasene $p\,v = \frac{2}{m}\,\theta$, therefore the thermation area is $\frac{2}{m}\,\theta\,\epsilon\,\log\frac{p}{p_0}$. On the diagram the height of the area thus swept out is θ; therefore, by omitting the factor θ from the expression for the area, we get $\frac{2}{m}\,\epsilon\,\log\frac{p}{p_0}$ as the horizontal dimension GP at any temperature, p being the pressure at G and p_0 the pressure at P.

The length AB $= \frac{501\cdot4 + 1\cdot0106 \times 273 - 1\cdot0106\,\theta}{\theta} = \frac{777\cdot3}{\theta} - 1\cdot0106$.

Denoting by the letter O the zero ordinate position at A 273, and measuring horizontally from O, we get by the graph for aquene heated to θ and then evaporated

$$\mathrm{OG} = 1\cdot0106\,\epsilon\log\frac{\theta}{273} + \frac{777\cdot3}{\theta} - 1\cdot0106 + \frac{7}{m}.$$

By the graph for water evaporated at the temperature of melting ice, or 273° absolute temperature centigrade, and heated at constant pressure up to θ, and then compressed as gasene at constant temperature to pressure p on the vapene curve G, we get

$$\mathrm{OG} = \frac{501\cdot4}{273} + \frac{7}{m} + \frac{7}{m}\,\epsilon\log\frac{\theta}{273} - \frac{2}{m}\,\epsilon\log\frac{p}{p_0}.$$

Equating these two values of OG and collecting the terms, we get

$$\log \frac{p}{p_0} = 3031 \cdot 405 \frac{\theta - \theta_0}{\theta\, \theta_0} - 5 \cdot 57507 \log \frac{\theta}{\theta_0}.$$

This gives the pressure p in multiples of the pressure p_0 at $273° = \theta_0$. It will be better to assume that the pressure at the boiling point of water, or 373°, is 760 millimètres of mercury, that is, "atmospheric pressure;" and to reduce the above formula to the following for pressure p in millimètres of mercury at any temperature θ :—

$$\log p = 25 \cdot 3453636 - \frac{3031 \cdot 405}{\theta} - 5 \cdot 57507 \log \theta.$$

We can now try what the run of pressures is by this formula, and compare it with Regnault's steam pressures :—

TABLE 4.

Comparison of Steam Pressures in Regnault's Experiments with those calculated by the author's formula for Vapene, that is for ideal gas at maximum pressure.

Temperature.	Pressure in millimètres of mercury. Regnault. Steam.	Formula. Vapene.
centig.	mm.	mm.
273°	4·6	4·566
323°	91·982	93·597
373°	760·	760·
423°	3581·2	3442·6
473°	11688·	10566·
503°	20926·	18083·

Here the two columns of pressures do not agree. Regnault's pressure in his experiment at the highest temperature is about 16 per cent. greater than that given by the formula for vapene.

Before leaving the diagram for gasene and vapene, there are certain important geometrical features to be noticed in it. The curves B, C, and G, Fig. 10, Plate 80, are the same curve in different

positions of entropy or longitude. The letters A, B, C, G, &c., referring to the theta-phi diagram, do not denote the particular points at which they happen to be placed in the diagram. Each letter denotes a curve or else a vertical line; and AB, AG, BC, BG, &c., denote the horizontal interval between these curves at any temperature θ. The area up to ACZ_3 represents the energy or heat possessed by the working substance at the temperature indicated by the line AG at $\theta = 453°$. The area Z_3CGZ_4 or $\theta \times CG$ is the pv of the substance; and this is not *possessed* by the substance. Part or all of $\theta \times CG$ represents external work done during evaporation; whether it is *part* or *all* of $\theta \times CG$ which represents this work depends upon how the evaporation has been accomplished. At any temperature the rate of shift of entropy on B, C, and G, is $AB \div \theta$ per degree of temperature; this is the immediate consequence of the equal-area property of the B curve (page 416).

$$AB = \frac{777 \cdot 3}{\theta} - 1 \cdot 0106 \quad \text{(page 417)}$$

$$CG = \frac{2}{m} = 0 \cdot 11136 \quad \text{(page 411)}$$

$$BC = \frac{5}{m} = 0 \cdot 27840 \quad \text{(page 411)}$$

$$BG = \frac{7}{m} = 0 \cdot 38976 \quad \text{(page 411)}$$

Critical Temperature.—The temperature at which the A curve and the B curve meet is the critical temperature for aquene and gasene, above which there can be no liquid.

In Fig. 13, Plate 81, let O be any point in the G curve in Fig. 10; that is, in the curve of gasene at maximum pressure, otherwise called vapene. Let OG and OP be tangent elements respectively of the curve G, and of the curve P starting from O. Let OK denote an infinitely minute increase of temperature, $d\theta$. Write $-dG$ to denote GK, the simultaneous shift of entropy on the curve G.

$$\text{Now } KP = \frac{7}{m}\frac{d\theta}{\theta}$$

$$\text{and } GP = \frac{2}{m}\frac{dp}{p} = \frac{2}{m} d\,(\epsilon \log p)$$

$$\therefore\ -\frac{dG}{d\theta}\,d\theta = GK = \frac{2}{m}\,\frac{dp}{p} - \frac{7}{m}\,\frac{d\theta}{\theta}$$

$$\therefore\ -\theta\,\frac{dG}{d\theta}\,d\theta = \frac{2}{m}\,\theta\,\frac{dp}{p} - \frac{7}{m}\,d\theta.$$

But $-\theta\frac{dG}{d\theta} = AB$ (page 416), and $\frac{2}{m}\theta = pv$ (page 408);

$$\therefore AB\,d\theta = v\,dp - \frac{7}{m}\,d\theta$$

$$\therefore v\frac{dp}{d\theta} = AB + \frac{7}{m} = AG.$$

$$\text{Since } pv = \frac{2}{m}\,\theta,$$

$$\text{therefore } p\frac{dv}{d\theta} + v\frac{dp}{d\theta} = \frac{2}{m}.$$

$$\text{Hence } -p\frac{dv}{d\theta} = (AB + \frac{5}{m}) = AC.$$

The above values for $v\,dp$ and $p\,dv$ have been obtained by considering the heating and compression of gasene. The same values are also arrived at when the heat of evaporation is considered. By the First Law the work done over the graph AG, GG, GA, AA, is AG $\times$ $d\theta$, when the difference of temperatures is $d\theta$: that is, as above, $(AB + \frac{7}{m})\,d\theta = v\frac{dp}{d\theta}\,d\theta$.

It is important in this investigation to observe that the same equation is arrived at, whether the state on the G curve in Fig. 10, Plate 80, is considered from the gasene side or from the evaporation side. When gasene is compressed at constant temperature, the vapene pressure is reached when the state-point crosses the G curve; and thereafter liquefaction is the result of further compression. The Second Law determines that for any one point there is only one state; whence it follows that the point at which gasification is completed in evaporation must also be the point at which liquefaction commences in compression at constant temperature.

So far as we are guided by our knowledge of the nature of steam, and of the requirements of the first and second laws of thermodynamics, there is no inconsistency in the existence of gasene and vapene. Such however is not the order of nature; and it is therefore necessary to discover what other order of pressures, volumes, and temperatures, would harmonise with these requirements.

The position of the G curve in Fig. 10, Plate 80, is that for vapene, that is, for completely gasified matter with its $pv = \frac{2}{m}\,\theta$. In nature the pv of actual steam is always $\frac{2}{m}\,x\,\theta$, and below the

critical temperature the coefficient x is always less than unity. Without anticipating investigation by any hypothesis as to what has happened to the gas to make its pv fall short of the value $\frac{2}{m}\theta$ assigned to it by the kinetic theory, and without making any actual experiment, we can, by reasoning on from the above principles, ascertain what alternative order is possible to replace that of gasene and vapene, which experiment teaches us is not the order of nature.

The principle according to which the theta-phi diagram is constructed being understood, it is obvious that a theta-phi graph may be drawn to represent any fully specified series of thermodynamic states, whether those states be such as occur in nature or merely imaginary. For an ideal graph now to be considered, let the conditions be the following. Let the unit mass consist of molecules of water, of which the quantity x are in motion as gasene at temperature θ; and the other portion, $z=1-x$, consists of separate molecules in the state of rest. By "separate" is meant that the particles are segregated single molecules. We have therefore x at temperature θ, and z at absolute zero of temperature. The pv will therefore be $=\frac{2}{m}x\theta$. The ideal problem now proposed is to describe the graph for change of temperature, say from $\theta = 473°$ to $\theta = 273°$, the pressure p and the volume v being maintained throughout the same as the p and the v for saturated steam at the same temperature. The values of p and v for any temperature are supposed to be given. Obviously the x will also be the same as for saturated steam. It must be borne in mind that in this paper the mechanical equivalent of the unit of heat is also the unit of work and the unit of energy.

As the temperature is diminishing, a portion of the molecules pass from the z class into the x class, becoming energized so as to possess $\frac{5}{m}\theta$ of energy per unit of mass, and in addition to perform $\frac{2}{m}\theta$ of work per unit of mass when in the act of assuming the pv due to the motion. The rate at which heat would have to be communicated would be therefore the sum of the rate at which work is done externally by expansion and the rate at which the possessed

energy is increased. The energy possessed by the active molecules at any instant is $\frac{5}{m}x\theta$, and the rate at which this amount varies is $\frac{5}{m}d(x\theta) = \frac{5}{m}xd\theta + \frac{5}{m}\theta dx$, where dx denotes the increase of the quantity of active molecules during the diminution of temperature denoted by $d\theta$. The work done in the same time will be pdv, which includes the pv of the newly energized molecules $= \frac{2}{m}\theta dx$.

In the sketch diagram, Fig. 14, Plate 81, let the curve E be the required graph. From E set out the curve B, so that at any temperature BE $= \frac{7}{m}x$; and also the curve G, so that EG $= \frac{7}{m}z$. At $\theta_0 = 273°$ the value of x is nearly equal to unity; and therefore, in the figure, the curves E and G seem to meet at $\theta_0 = 273°$. Strictly at that temperature EG $= 0\cdot000119$ and EF $= 0\cdot000085$, the length BG being $\frac{7}{m} = 0\cdot38976$; this will be explained further on. Through the point at five-sevenths of EG from E at $\theta_0 = 273°$ draw the curve P, which is the graph for gasene increasing in temperature at constant pressure, according to the equation $d\phi = \frac{7}{m}\frac{d\theta}{\theta}$. From the P curve set off the F curve, which is the graph for gasene having the same pressure as saturated steam at the same temperature, according to the equation FP $= \frac{2}{m}\epsilon \log \frac{p}{p_0}$, where p is the pressure of saturated steam at temperature θ, and p_0 the pressure at $\theta_0 = 273°$. Denote the $d\phi$, or element of horizontal travel on the different curves, by their respective letters, thus dB, dE, dF, dG, dP: positive for travel to the right, and with the negative sign for travel to the left.

Let us now ascertain how these curves are related to the pressure p, the volume v, and the x and the z of saturated steam. Write V for the volume of gasene on the curve F; we have therefore $v = xV$. Write also λ = the latent heat of evaporation at θ. Descending along E, the heat communicated is

$$\theta d\mathrm{E} = pdv + \frac{5}{m}xd\theta + \frac{5}{m}\theta dx$$

$$d(pv) = vdp + pdv = \frac{2}{m}xd\theta + \frac{2}{m}\theta dx;$$

$$\therefore \theta d\mathrm{E} = -vdp + \frac{7}{m}xd\theta + \frac{7}{m}\theta dx.$$

But by construction $\theta d\mathrm{G} = \theta d\mathrm{E} - \frac{7}{m}\theta dx$

$$\therefore \quad \theta d\mathrm{G} = -\,v dp + \frac{7}{m}x d\theta$$

$$\therefore \quad v\frac{dp}{d\theta} = -\,\theta\frac{d\mathrm{G}}{d\theta} + \frac{7}{m}x.$$

But according to elementary thermodynamics

$$v\frac{dp}{d\theta} = \frac{\lambda}{\theta}.$$

Let the curve A be now set out from E, making $\mathrm{AE} = v\frac{dp}{d\theta} = \frac{\lambda}{\theta} = \mathrm{AB} + \mathrm{BE}$; therefore $v\frac{dp}{d\theta} = \mathrm{AB} + \frac{7}{m}x$; therefore $\mathrm{AB} = -\,\theta\frac{d\mathrm{G}}{d\theta}$. Along G the sign of $d\mathrm{G}$, which is the element of horizontal travel $d\phi$ along the curve G, is the opposite of that of $d\theta$; the right-hand member of this last equation is therefore really positive, although it has to be written with the negative sign.

Now although this diagram has been constructed according to merely imaginary conditions, the $v\frac{dp}{d\theta}$ values given by the diagram are those for the actual v, p, dp, and $d\theta$, for the saturated steam which engineers have to deal with practically. If therefore a theta-phi diagram be drawn for practical saturated steam, in which an A curve represents the graph for aquene and an E curve the graph for saturated steam, as is done in Fig. 24, Plate 86, we shall have on this diagram also $\mathrm{AE} = v\frac{dp}{d\theta}$, where the $v\frac{dp}{d\theta}$ is the same as before; and therefore AE in the practical diagram, Fig. 24, will have the same length as AE in the ideal diagram, Fig. 14. We shall have also $\mathrm{BE} = \frac{7}{m}x$ in the practical diagram, the same as in the ideal diagram. This equality would however also be obtained in any diagram made by shearing the ideal diagram horizontally in any fashion, leaving AG 273 undisturbed. This equality alone is therefore not sufficient to prove that the ideal diagram in Fig. 14 as described is identically that for practical steam. We have not up to this point introduced any guide for how the curves are to run in the practical diagram, Fig. 24, Plate 86; we have only ascertained what their distances apart must be at any temperature. In the ideal diagram, Fig. 14, Plate 81, the curves are all fixed by the

given volume v and pressure p for saturated steam; and we can now compare the A curve, so fixed, with what we know about the A curve in the practical diagram, Fig. 24. The ideal diagram, Fig. 14, gives the heat of segregation constant at all temperatures; because $AB = -\theta\frac{dB}{d\theta}$, since the B curve is the same as the G curve (page 416). That is, the area up to the segregation curve B, bounded by the B vertical, the θ horizontal, the A curve, and the base line, is constant. For the A curve, when the calculations are actually made according to the run of pressures obtained experimentally by Regnault, the ideal diagram, Fig. 14, gives $dA = 1\cdot0106\frac{d\theta}{\theta}$ a constant, as the specific heat of aquene; and $1\cdot0106\frac{d\theta}{\theta}$ is also what the specific heat of water was found to be by Rowland for the calorimetric temperatures in Regnault's experiments. The specific heat of water at any temperature is greater than the specific heat of aquene by the amount $\theta\frac{d}{d\theta}\left(v\frac{dp}{d\theta}\right)$, a quantity so extremely small at the low temperatures in Regnault's experiments that any error introduced by neglecting it altogether in setting out the A curve could not be appreciated in working from experimental steam pressures. The v in the above expression is the volume of unit mass of liquid; and it has to be taken according to the unit employed in this paper. The ideal A curve in Fig. 14 is therefore the A curve of the practical diagram, Fig. 24, according to Regnault's experiments.

The total heat according to the ideal diagram, Fig. 14, Plate 81, will be shown to be also just that ascertained to be the total heat of saturated steam in Regnault's experiments, and therefore just that which the practical diagram, Fig. 24, Plate 86, ought to give. The notion which prevailed before the publication of this investigation, that as x diminished the heat of segregation also diminished, is not countenanced by the tendency of the non-agreements shown in Fig. 20, Plate 82. The specific heat of steam, according to which the $\frac{7}{m}x$ is set off in the ideal diagram, Fig. 14, Plate 81, is also strictly in accordance with the specific heat of steam given by Regnault's experiments, as explained at page 408. It is after taking

away the $\frac{7}{m} x\theta$ from the total heat that the constant remainder is obtained, denoting that the heat of segregation is constant in actual saturated steam at the temperatures included in the experiments, irrespective of the variation of x, as it is also constant on the ideal diagram.

The Second Law is in every respect complied with, when the ideal diagram as described above is admitted to be the practical diagram. While, to the mind of the author, these grounds seem to be sufficient to justify the conclusion that the above ideal diagram, Fig. 14, is also identically the practical theta-phi diagram, Fig. 24 for water and steam, he at the same time desires very emphatically to state that the ideal conditions of the molecules—as forming two classes, one at rest and the other in motion—are not supposed by him to be the actual conditions. It is not meant that certain molecules are really uniformly active, and the remainder absolutely idle; but only that, in respect of pressure, volume, and temperature, the thermodynamic states in steam, according to these experiments, are the same as they would be if unit mass were made up of x uniformly active molecules or *ergules*, and z absolutely inactive molecules or *argules*. The root *erg* signifies activity, and the root *arg* idleness. According to this view the temperature is proportional to the motion energy per ergule. This statement is however no extension of knowledge; it is merely an arithmetical form of the definition of ergule.

The ideal diagram, Fig. 14, Plate 81, which has now been discussed, has been constructed according to known values of the pressure p for the various temperatures. The curve F, for gasene having the same pressure as saturated steam at the same temperature, has now to be studied in relation to the curves G and P, in order afterwards to arrive at F without a previous knowledge of these temperature-pressures. Returning to the equation for dG, and writing from it the similar equation for dF, we have V instead of v, and $\frac{7}{m} d\theta$ instead of $\frac{7}{m} xd\theta$; because along F we have $x = 1$. We can also write xV for v; and then the two equations become (page 423)

$$\theta d\mathrm{G} = -xVdp + \frac{7}{m} xd\theta$$

2 N 2

$$\text{and } \theta dF = -Vdp + \frac{7}{m}d\theta.$$

Therefore for the same $d\theta$ we get $dG = xdF$.

When gasene is expanded at constant temperature, the state-point moves horizontally to the right, and the pressure falls according to the equation $d\phi = -\frac{2}{m}\frac{dp}{p} = \frac{2}{m}\frac{dV}{V}$. For any such gasene state-point there will also be a set of relative points corresponding to the B, E, and G points. Retaining the capital letters to denote points on the fixed curves, the corresponding small letters will be employed to denote the similarly related points to the right of these curves, that is, in the gasene or gas field of the diagram. The state-point for expanded gasene will be therefore denoted by f, Fig. 14, Plate 81; and on the same temperature line e will be the state-point for actual steam, expanded until it has the same pressure as gasene at the point f. The relative points b and g will be at $be = \frac{7}{m}x$, and $eg = \frac{7}{m}z$. The point f_1 at $ef_1 = \frac{5}{m}z$ will also be important in this investigation; it will more generally be regarded in its relation to g, namely as $f_1\,g = \frac{2}{m}z =$ the entropy of the defect of pv below the pv of gasene at that temperature. It will be subsequently shown that for steam f_1 is substantially identical with f; and therefore f_1 and F_1 will not appear in the diagrams.

What takes place during change of volume of gas at constant temperature will now be discussed, referring to the pee-vee diagrams, Figs. 15, 16, and 17, Plate 81; the text applies to any of these three diagrams. The expansion curve is CCC; at any instant the volume is $v =$ BC. For gasene at the same pressure the volume would be AC. The line AA is got by setting back from C the length AC $= \frac{2}{m}\theta \div p$. In Fig. 15, the A path is vertical: so that, including AB, the complete diagram is that for gasene. In Fig. 16, A travels to the left in ascending; and in Fig. 17, A travels to the right in ascending. In these examples x is less than unity, as it is in ordinary steam, and therefore the A line is outside the pee-vee diagram. In Fig. 15 pv *de*creases with compression, and the decrease is proportional to the variation of pressure. In Fig. 16

also pv *decreases* with compression, but not in any particular ratio. In Fig. 17 pv *increases* with compression, but not in proportion to the increase of pressure. However x may vary, the area swept by the C vertical inwards must be equal to the sum of the areas swept by AC and AA outwards, because pV is constant. Or the area swept by the C vertical inwards is always equal to the area swept by BC upwards, added to the increase of the AB rectangle.

$$\text{The BC rectangle} = pv = pxV = \frac{2}{m}x\theta.$$

$$\text{The AB rectangle} = p(V-v) = pzV = \frac{2}{m}z\theta.$$

$$\text{The area swept by CC} = -pdv = \text{the work element.}$$

$$\text{,, ,, by BC} = vdp = xVdp = \frac{2}{m}\theta x\frac{dp}{p}.$$

$$\text{,, ,, by AB} = zVdp = \frac{2}{m}\theta z\frac{dp}{p}.$$

$$\text{,, ,, by AA} = p\,d(zV).$$

$$\text{The increase of the AB rectangle} = \frac{2}{m}\theta dz = zVdp + p\,d(zV);$$

$$\therefore -pdv = xVdp + zVdp + p\,d(zV).$$

If as in Fig. 15 the length AB does not vary, then

$$-pdv = xVdp + zVdp = -pdV,$$

$$\text{or } \theta df = \theta dg \quad - \theta d\overline{fg} = \text{the work element.}$$

For the element $\theta d\overline{ef}$ the action is merely a transfer of heat. During expansion, $-\theta d\overline{ef}$ of the heat imparted remains in the gas, as the gas-heat of newly energized molecules. The work done by this heat $(-\theta d\overline{ef})$ is wholly internal during expansion at constant temperature. Again during compression at constant temperature, when a portion of the ergules become argules, the gas-heat abandoned represents no portion of the work of compression. If any heat of segregation were transferred during expansion or compression at constant temperature, neither would any portion of it be represented in the work done by or upon the substance. As the diagram is being worked out according to the conclusion that the heat of segregation is constant for all state-points in the gas field, it is unnecessary to complicate the investigation with any relative point to indicate merely imaginary changes in its amount.

In compression at constant temperature the transfer of energy consists of three elements; two of these are work elements, and the third is heat only. The work of compression consists of the element of work by which the pressure is changed, and the element of work by which pv is changed. The term *appression* will be employed to denote the former, and *collapse* to denote the latter. The heat emitted, due to the energy abandoned by ergules when becoming argules, will be called the collapse-heat. We have then during compression

$$\text{Work} = \text{appression} + \text{collapse}$$
$$\text{or} - pdv = vdp + d(pv)$$
$$\text{Heat abandoned} = \text{appression} + \text{collapse} + \text{collapse-heat}$$
$$\text{or} - \theta de = -\theta dg + \theta d\overline{fg} + \theta d\overline{ef}.$$

If the f graph be not horizontal, the relative points e and g will accompany f, each maintaining its proper distance from f, and the investigation at the top of page 426 will also hold good for these; and consequently we get for any arbitrary graphs $xdf = dg$, the same as for the F and G graphs. Let the f graph be a cycle, a vertical rectangle, the vertical sides being only $d\phi$ apart. Along the vertical graphs, whatever x may be, dg must be $= 0$, because $df = 0$. The g graph is therefore also a vertical rectangle. Regarding the horizontal dimensions as df and dg in the two rectangles, we have the same ratio between these over the whole length. Now the ratio of dg to df is equal to x; therefore x must be constant for vertical graphs, that is, x is constant during adiabatic action in superheated steam over the area for which the condition, heat of segregation a constant, holds good.

The area swept to the left, in Fig. 16, Plate 81, by the A vertical during compression, is equal to the excess of the area swept to the left by the f_1 vertical over that swept to the left by the f vertical, in Fig. 14. When during compression at constant temperature pv increases proportionally to the increase of pressure, the expansion curve is of the same type as in Fig. 15, in which the A vertical is stationary; and therefore the travel of f is then the same as the travel of f_1. If this relation holds good from P to F in Fig. 14, the point f will coincide throughout with the point f_1, and

F will be identically F_1; and there is only one curve which will satisfy this identity. When f and f_1 are taken to be identically the same points, the equations $F_1\,G = \frac{2}{m} z$ and $\frac{dG}{d\theta} = x \frac{dF}{d\theta}$ become simultaneous equations when F is written for F_1. When these are solved as simultaneous equations, a definite value of x is thereby determined for each temperature, and also the ratio in which the pressure of saturated steam must vary with temperature. The total heat of steam at one temperature is the only experimental quantity required, and it is not permitted to introduce any empirical constant to modify the result. The investigation will now be continued, and the calculations made to verify this solution of the problem; that is, to establish that it gives the same series of temperature-pressures as was obtained by Regnault.

It has now to be ascertained, according to these two simultaneous equations, how x varies with the temperature. It has been shown (page 426) that $dG = x\,dF$, Fig. 14, Plate 81, and Fig. 24, Plate 86;

$$\therefore \frac{dG}{d\theta} = x \frac{dF}{d\theta}$$

$$\therefore \frac{d\,.\,FG}{d\theta} = \frac{1-x}{x} \frac{dG}{d\theta}$$

but $FG = \frac{2}{m} z$, as above; and $\frac{dG}{d\theta} = \frac{AB}{\theta}$ (page 423);

$$\therefore \frac{2}{m} \cdot \frac{dz}{d\theta} = \frac{z}{1-z} \frac{AB}{\theta}$$

$$\therefore \frac{2}{m} dz = AB \,.\, \frac{z}{1-z} \frac{d\theta}{\theta}.$$

Write $c = 1 \cdot 0106$ = the specific heat of water (page 405),

and $S = 777 \cdot 3 = 501 \cdot 4 + 273\,c$ = the heat of segregation,

then $AB = \frac{S - c\theta}{\theta}$, as on page 417;

$$\therefore \frac{2}{m} \frac{1-z}{z} dz = \frac{S - c\theta}{\theta^2} d\theta \qquad (1)$$

$$\text{or } \frac{2}{m} \frac{dz}{z} - \frac{2}{m} dz = \frac{S\,d\theta}{\theta^2} - \frac{c\,d\theta}{\theta}.$$

Integrating, $\frac{2}{m} \epsilon \log z - \frac{2}{m} z = -\frac{S}{\theta} - c\,\epsilon \log \theta +$ constant.

Substituting FG and changing signs,

$$FG - \frac{2}{m} \epsilon \log \left(\frac{m}{2} FG\right) = \frac{S}{\theta} + c\,\epsilon \log \theta - \text{constant}. \qquad (2)$$

From (1) we get what the value of θ is when $z = 1$, for it gives then $S = c\theta$; therefore $\theta = \frac{777 \cdot 3}{1 \cdot 0106} = 769 \cdot 147$; also when $z = 1$, we

TABLE 5.—*Values of* $\mathrm{FG} - \frac{2}{m} \epsilon \log \left(\frac{m}{2}\mathrm{FG}\right) = a.$

FG	a	FG	a
0·00001	1·03765	0·0020	0·44963
0·00002	0·96046	0·0025	0·42528
0 00003	0·91565	0·0030	0·40547
0·00004	0·88337	0·0035	0·38880
0·00005	0·85847	0·0040	0·37444
0·00006	0·83817	0·0045	0·36182
0·00007	0·82102	0·0050	0·35059
0·00008	0·80616	0·0055	0·34047
0·00009	0·79305	0·0060	0·33128
0·00010	0·78133	0·0070	0·31512
0·00013	0·75214	0·0080	0·30125
0·00016	0·72905	0·0090	0·28913
0·00020	0·70424	0·0100	0·27840
0·00030	0·65919	0·0110	0·26878
0·00040	0·62725	0 0120	0·26009
0·00054	0·59397	0·0130	0·25218
0·00060	0·58230	0·0140	0·24493
0·00070	0·56523	0·0150	0·23824
0·00080	0·55046	0·0160	0·23206
0·00090	0·53745	0·0170	0·22631
0·00100	0·52581	0·0180	0·22094
0·00120	0·50571	0·0190	0·21618
0·00140	0·48874	0·0200	0·21121
0·00160	0·47407	0·0210	0·20677
0·00180	0·46116		

TABLE 6.—*Values of* $\frac{S}{\theta} + c\,\epsilon \log \theta - 7 \cdot 61496 = b$.

θ	b	θ	b
273·00	0·90122	407·51	0·36625
275·34	0·88569	411·98	0·35658
278·98	0 86216	413·00	0·35442
282·93	0·83740	418·26	0·34353
289·42	0·79872	426·90	0·32659
293·00	0·77832	433·00	0·31528
294·41	0·77280	434·16	0·31318
299·76	0·74152	440·40	0·30224
304·95	0·71476	448·63	0·28857
309·17	0·69386	453·23	0·28139
313 00	0·67554	455·99	0·27705
312·28	0·67422	459·33	0·27193
321·99	0·63483	462·11	0·26795
326·42	0·61559	465·81	0·26265
333·00	0·58898	467·46	0·26031
335·04	0·58094	473·00	0·25273
343·44	0·54923	476·31	0·24839
351·95	0·51922	481·27	0·24204
353 00	0·51562	485·19	0·23718
360·47	0·49119	490·81	0 23048
368·74	0·46576	493·00	0·22794
373·00	0·45330	498·00	0·22231
380·00	0·43370	503·00	0·21690
390·00	0·40751	508·00	0·21175
393·00	0·40003	513·00	0·20666
398·70	0·38630	519·00	0·20080

have $FG = \frac{2}{m} = 0 \cdot 11136$. Inserting this value and making $\theta = 769 \cdot 147$, the constant is found to be $7 \cdot 61496$. The left-hand member of equation (2) is then calculated for all required values of FG, and tabulated under the letter a in Table 5. The right-hand member is also calculated for all required values of θ, and tabulated under the letter b in Table 6.

A curve is then drawn with FG set off on the horizontal axis and a on the vertical axis. In Fig. 23, Plate 85, this curve is shown in three pieces, lettered CC, BB, AA. This was done on accurate sectional paper, the a ordinates varying from 20 inches to 8 feet. With the b ordinates for any temperature θ this diagram can be used as a table of values of FG. At the b ordinate on the curve, the value of FG for that temperature θ can be read off. For more convenient reference another curve was then set out from these values, giving FG vertically and the temperature θ horizontally. This curve is also given in Fig. 23 in two sections FF and GG. The following values for FG have been obtained in this way:—

TABLE 7.—*Values of* FG *at different temperatures.*

Temperature Centigrade.	Value of FG.	Temperature Centigrade.	Value of FG.	Temperature Centigrade.	Value of FG.
273	0·000034	353	0·001106	443	0·00828
283	0·000062	363	0·001472	453	0·00971
293	0·000103	373	0·001925	463	0·01123
303	0·000168	383	0·002501	473	0 01293
313	0·000263	393	0·00314	483	0·01474
323	0·000395	403	0·00392	493	0·01670
333	0·000568	413	0·00483	503	0·01881
343	0·000801	423	0·00585	513	0·02102
		433	0·00699		

The value of x, being $1 - z$, is $x = 1 - \frac{FG}{0 \cdot 11136}$.

Total Heat of Saturated Steam.—At this stage of the investigation the total heat of saturated steam at any temperature can be calculated. It is

$$501 \cdot 4 + \frac{7}{m} x\theta = 501 \cdot 4 + (0 \cdot 38976 - \tfrac{7}{2} FG)\theta,$$

in the units employed in this paper. The accompanying Tables 8, 9, 10, show for comparison Regnault's results and those obtained by the above formula, dividing the latter by $1 \cdot 0106$ to bring them to Regnault's units. For convenience the common centigrade

TABLE 8.—*Total Heat of Saturated Steam, in Regnault's units, for Low temperatures.* (*See Fig.* 18, *Plate* 82.)

Temp. centig.	A Experi-ments.	B Formula.	C A–B	Temp. centig.	A Experi-ments.	B Formula.	C A–B
−2·0	608·1	600·7	7·4	8·6	614·1	605·0	9·1
−0·2	601·5	601·4	0·1	8·6	603·0	605·0	−2·0
0·0	605·8	601·4	4·4	9·0	611·6	605·1	6·5
2·0	613·0	602·4	10·6	11·4	602·7	606·1	−3·4
5·2	611·9	604·7	7·2	11·8	605·1	606·2	−1·1
6·4	619·7	604·1	15·6	13·5	614·3	606·9	7·4
7·4	614·5	604·5	10·0	14·0	609·9	607·1	2·8
7·6	612·6	604·6	8·0	14·7	615·5	607·4	8·1
8·5	611·3	605·0	6·3	16·1	613·0	602·4	10·6

temperatures are given in these Tables, and not the absolute temperatures, although θ in the formula denotes the absolute temperature.

Regnault states that these experiments were made designedly under very dissimilar conditions, often unfavourable to exactitude. He considers that the total heat for 10° is not far from 610 units. The formula gives 605·2 for that temperature. At temperature 100°, thirty-eight experiments gave the total heat varying from 635·6 to 638·4, the general mean being 636·68. The formula gives 637·51, the difference is therefore −0·83. In Table 9 the temperatures taken are those given by Regnault as calculated from the pressures.

In these Tables several experiments at nearly the same temperature are frequently averaged and entered in one line. The last five lines in Table 10, comprising seventeen experiments, show an abnormal increase of total heat in the experiments. The author thinks there must have been some oversight in tabulating the results above 176°.

TABLE 9.—*Total Heat of Saturated Steam, in Regnault's units, for Medium temperatures.* (*See Fig.* 19, *Plate* 82.)

Temp. centig.	A Experiments.	B Formula.	C A–B	Temp. centig.	A Experiments.	B Formula.	C A–B
63·0	625·5	624·9	+0·6	80·4	628·8	631·0	−2·2
65·3	623·8	625·7	−1·9	80·6	627·7	631·0	−3·3
68·0	622·5	626·6	−4·1	81·0	628·8	631·3	−2·5
69·7	626·4	627·3	−0·9	82·7	631·0	631·8	−0·8
70·5	626·9	627·6	−0·7	83·1	628·9	632·0	−3·1
71·1	622·2	627·9	−5·7	84·9	629·9	632·6	−2·7
71·3	624·4	627·9	−3·5	85·2	631·7	632·7	−1·0
76·5	628·6	629·7	−1·1	85·2	628·6	632·7	−4·1
78·3	627·0	630·3	−3·3	86·0	628·4	633·0	−4·6
79·5	630·1	630·8	−0·7	87·8	633·1	633·6	−0·5
80·2	630·2	631·0	−0·8	88·1	633·4	633·7	−0·3

The nature of this increase is better shown in Fig. 20, Plate 82, where the differences tabulated in column C of Table 10 are plotted. Tables 8 and 9 are also plotted in Fig. 18 and Fig. 19 respectively. The rectangle at 100° in Fig. 19 encloses the results of thirty-eight experiments, giving a general mean at the spot marked. To judge properly of the degree of corroboration afforded by these results, it must be borne in mind that the zero line for Figs. 18, 19, 20 is always more than five feet below the datum line. Even in Fig. 18 the maximum error is remarkably small when the conditions of the experiment are taken into account. The datum line is here fixed quite independently of these total-heat experiments. It is calculated from the steam pressures observed by Regnault.

That F_1 is identical with F (pages 426 and 429), which is now being verified, implies important relations, the most remarkable of which is

TABLE 10.—*Total Heat of Saturated Steam, in Regnault's units, for High temperatures.* (*See Fig.* 20, *Plate* 82.)

	A	B	C		A	B	C
Temp. centig.	Experiments.	Formula.	A–B	Temp. centig.	Experiments.	Formula.	A–B
119·4	642·1	643·3	−1·2	150·2	652·6	650·8	1·8
119·2	642·3	643·2	−0·9	153·5	650·1	651·4	−1·3
119·6	641·9	643·3	−1·4	154·1	650·2	651·5	−1·3
122·2	642·2	644·0	−1·8	155·2	651·1	651·8	−0·7
122·3	642·2	644·1	−1·9	156·1	652·1	652·0	0·1
125·3	643·7	644·9	−1·2	157·4	651·7	652·2	−0·5
127·1	644·8	645·3	−0·5	160·3	653·2	652·7	0·5
129·0	645·1	645·8	−0·7	161·8	654·1	653·0	1·1
134·3	648·2	647·3	0·9	164·7	654·5	653·5	1·0
135·3	647·9	647·4	0·5	171·6	655·5	654·2	1·3
136·9	647·5	647·8	−0·3	172·7	655·6	654·3	1·3
138·1	647·8	648·1	−0·3	173·2	656·0	654·7	1·3
142·2	648·6	649·0	−0·4	174·0	656·0	654·9	1·1
143·4	650·3	649·3	1·0	175·4	656·1	655·0	1·1
144·3	649·5	649·5	0·0	179·6	662·3	655·6	6·7
145·4	649·7	649·9	−0·2	183·5	662·4	656·0	6·4
146·5	651·1	650·0	1·1	186·0	664·7	656·3	8·4
147·6	649·6	650·2	−0·6	188·1	664·7	656·5	8·2
149·0	652·8	650·5	2·3	194·4	665·4	657·1	8·3

that the order in which x varies is that which gives for isothermal compression the same pee-vee curve as for gasene between the same pressures and at the same temperature: or $-pdv = \frac{2}{m}\theta\left(x\frac{dp}{p} + dz\right) = -p\,dV$, in which v is the gas volume and V the gasene volume for

the same pressure p and the same temperature θ. The appression element in the above is $\frac{2}{m}\theta\, x\frac{dp}{p}$, and the collapse element is $\frac{2}{m}\theta\, dz = \frac{2}{m}\theta z\frac{dp}{p}$.

The heat given out during the compression from P to e in Fig. 14, Plate 81, is made up (page 428) of

appression + collapse + collapse-heat = heat abandoned;

$$\text{or} \qquad \theta.\overline{Pg} \quad + \quad \theta.\overline{gf} \quad + \quad \frac{5}{m}z\theta \quad = \quad \theta.\overline{Pe}$$

neglecting the magnitude fg at P, which is too minute to be represented. This magnitude however is not omitted in the calculations which are given further on. The sum of the appression and collapse is $\theta \times \overline{Pf}$, which must consequently be the energy area of the pee-vee diagram of the compression. Therefore the sum of the work of appression and collapse in compressing steam is equal to the work of compression in gasene between the same pressures at constant temperature. The $p\,dv$ in gasene compression on the pee-vee diagram is that of the common hyperbola; therefore the $p\,dv$ for the compression curve of steam is also that represented by the common hyperbola. In other words, the isothermal expansion curve is not affected by the value of x. It is only the expansion *curve* that is here referred to, and not the pee-vee diagram as a whole.

The type of pee-vee diagram for isothermal expansion is that shown in Fig. 15, Plate 81. The curve is drawn as if it were for gasene, and consequently as if the volume were AC $= \frac{2}{m}\frac{\theta}{p}$; whereas the actual volume is only BC $= \frac{2}{m}x\frac{\theta}{p}$. As the pressure increases, the ratio BC $\div$ AC $= x$ is continually diminishing. Writing $z = 1 - x =$ AB $\div$ AC, it is obvious that z is proportional to the pressure at any one temperature. The fictitious volume AB is constant for the same temperature, but different for different temperatures. The equation representing the relation between pv and temperature θ is therefore $\frac{2}{m}\theta = p\left\{v + f(\theta)\right\}$, where $f(\theta)$ is a function of the temperature; it is $f(\theta) = \theta\frac{\text{FG}}{p}$, which is a constant for the same temperature.

We are now able to state as follows what is the critical condition that determines at what entropy liquefaction shall commence when actual steam is compressed at constant temperature:—namely when, during the process of compression, the appression point in entropy crosses the vapene curve G in Fig. 10, Plate 80, liquefaction commences and appression ceases.

What is the pressure when, during compression, liquefaction takes place at any particular temperature? It is the pressure which gasene would have if compressed to such an extent that the work expended in its compression is equal to that required for both appression and collapse in steam; or, in other words, it is the pressure which steam has when its appression point crosses the vapene curve. That is to say, let gasene at G 273° in Fig. 14, Plate 81, be taken along P to $\theta = 473°$, and then back along the horizontal line of temperature $\theta = 473°$ to F, still continuing as gasene; its pressure will then be that of saturated steam, for which the entropy point on the horizontal line of 473° temperature is E, and the length of FG is such that $\theta \times \mathrm{FG} = \Delta\, pv$ between gasene and saturated steam at that temperature, or $= \frac{2}{m} z\, \theta$ (page 429). What has now been shown is, that if p denotes the pressure of saturated steam at temperature θ, the locus of the state-point of gasene at the same pressure is at a distance of $\frac{2}{m} z$ from G, which is the point of complete gasification, if that were possible at the instant of evaporation. Such an overlapping would violate the Second Law; but we have found that Nature avoids the overlapping by a suitably apportioned reduction of pv all the time that compression is going on: so that the pressure of saturation is attained just at that point where appression alone arrives at the curve G which is the boundary of complete gasification. At that instant $\mathrm{EG} = \frac{5}{m} z + \frac{2}{m} z = \frac{7}{m} z$. The value of AB in Fig. 15, Plate 81, can therefore be calculated from the saturated-steam value of $\theta \frac{\mathrm{FG}}{p}$. The investigation will now be continued, making F identical with F_1, and f with f_1, according to Regnault's temperature-pressures for steam.

Since zV is constant at constant temperature, and $pzV = \frac{2}{m} z\theta$ at any temperature (page 427), therefore at constant temperature p is proportional to z; therefore at constant temperature $\frac{p}{p_0} = \frac{z}{z_0}$, where p and p_0 are any two pressures, and z and z_0 the corresponding values of z. Consequently along any temperature line we have $\frac{2}{m} \epsilon \log \frac{p}{p_0} = \frac{2}{m} \epsilon \log \frac{z}{z_0}$. But $f_0 - f = \frac{2}{m} \epsilon \log \frac{p}{p_0}$; therefore $f_0 - f = \frac{2}{m} \epsilon \log \frac{z}{z_0}$. But z is constant along vertical lines in the gas field (page 428); therefore the horizontal distance between any two f points in the gas field, whether these be on the same temperature line or not, is $f_0 - f = \frac{2}{m} \epsilon \log \frac{z}{z_0}$. Therefore $\mathrm{F}_0 - \mathrm{F} = \frac{2}{m} \epsilon \log \frac{z}{z_0}$; and the calculations of the temperature-pressures given in Table 11 (pages 442–5) verify these z values along the F curve, and therefore also along the E and G curves. We have therefore the z values verified by Regnault's experiments for the whole area of the gas field included in the range of temperatures dealt with in the experiments, not only for saturated steam but also for steam expanded at constant temperature out to the entropy vertical for saturated steam at $\theta = 273°$. As according to the Second Law any state-point denotes the same conditions of the working substance, by whatever form of graph it may be reached, therefore for any order of expansion or compression the value of z is verified by these experiments over the whole area enclosed by the graph F 503 K 503 P 273 F 503, Fig. 24, Plate 86.

The values of FG employed in the pressure calculations were originally obtained by the method of cross curves, as explained above. The author has also devised an alternative method, which can be more easily applied when the pressure for only one temperature has to be calculated. It has been shown that the horizontal distance between F for z and f_0 for z_0 is

$$\frac{2}{m} \epsilon \log \frac{z}{z_0} = \frac{2}{m} \epsilon \log \frac{p}{p_0} = f_0 - \mathrm{F}.$$

Therefore $\mathrm{F}_0 - \mathrm{F} = \frac{2}{m} \epsilon \log \frac{p}{p_0} - \frac{7}{m} \epsilon \log \frac{\theta}{\theta_0} = \frac{2}{m} \epsilon \log \frac{z}{z_0}$.

That is FK = FP − KP = FK.

Multiplying by $\frac{m}{2}$ and transposing,

$$\epsilon \log \frac{z}{z_0} = \epsilon \log \frac{p}{p_0} - \frac{7}{2} \epsilon \log \frac{\theta}{\theta_0}$$

$$\therefore \quad \log \frac{z}{z_0} = \log \left\{ \frac{p}{p_0} \left(\frac{\theta_0}{\theta} \right)^{\frac{7}{2}} \right\}$$

$$\therefore \quad z = (p \div \theta^{\frac{7}{2}}) \times (z_0 \, \theta_0^{\frac{7}{2}} \div p_0)$$

$$\therefore \quad \frac{2}{m} z = \frac{2}{m} \times (p \div \theta^{\frac{7}{2}}) \times (z_0 \, \theta_0^{\frac{7}{2}} \div p_0) = \text{FG};$$

or z and also FG are proportional to $p \div \theta^{\frac{7}{2}}$, because z_0 θ_0 and p_0 are constant. This will be introduced into a modification of the pressure formula to be now given, but it will not affect the calculations given in the tables and in the diagrams.

Pressure of Steam.—The final test of all the theorizing herein set forth is to apply the relations here deduced to the determination of the pressures of steam throughout the range of temperatures included in Regnault's experiments. Referring to the theta-phi diagram, Fig. 24, Plate 86, and reading it as it has been explained, we get $\text{OF}_0 + \frac{7}{m} \epsilon \log \frac{\theta}{\theta_0} + \text{FG} - 1 \cdot 0106 \; \epsilon \log \frac{\theta}{\theta_0} - \frac{777 \cdot 3}{\theta} + 1 \cdot 0106 - \frac{7}{m} = \frac{2}{m} \epsilon \log \frac{p}{p_0}$. Here the suffix $_0$ denotes that the value is to be taken for the temperature 273°. The terms in this equation are the equivalents of OP + FG − OG = FP; because $\text{OP} = \text{OF}_0 + \frac{7}{m} \epsilon \log \frac{\theta}{\theta_0}$; $\text{OG} = \text{OA} + \text{AB} + \text{BG}$; $\text{OA} = 1 \cdot 0106 \times \epsilon \log \frac{\theta}{\theta_0}$; $\text{AB} = \frac{777 \cdot 3}{\theta} - 1 \cdot 0106$; $\text{BG} = \frac{7}{m}$; $\text{FP} = \frac{2}{m} \epsilon \log \frac{p}{p_0}$. The value of p_0 is obtained in millimètres of a column of mercury by writing p at 373° equal to 760 millimètres. The formula then yields $p_0 = 4 \cdot 4886$ mm. of mercury. The mean of sixty-four experiments at 273° is 4·587, so that the difference is less than one-tenth of a millimètre, or less than 1–250th of an inch of mercury. The true steam pressure ought to be less than that shown by experiment at very low temperatures, because the great difficulty Regnault had to contend with at those low temperatures was the unavoidable slight residue of air in the water, which would add its pressure to that of the steam.

When the terms in the equation are collected and arranged conveniently for calculation, the following practical formula is

obtained for pressure in millimètres of mercury: Log p = $[0\cdot5910552]$ FG $+ 25\cdot3379 - [0\cdot7462505] \log \theta - [3\cdot4816439] \frac{1}{\theta}$. When the pressure is required in pounds per square inch the constant to be used is $23\cdot62419$. The numbers in brackets are the common logarithms of the numerical coefficients. Since FG is proportional to $p \div \theta^{\frac{7}{3}}$, we get $[0\cdot5910552 + \text{constant}] \times p \div \theta^{\frac{7}{3}} = [0\cdot5910552]$ FG. The constant can be obtained by calculating FG accurately for one temperature by equation (2) page 429, getting $a = b$ by trial. This has been done for $\theta = 473°$, for which $a = b = 0\cdot25273$, and FG $= 0\cdot012928$, in Tables 5 to 7, pages 430–432; and the constant required comes out to be $3\cdot40675$. The new term is therefore, for millimètres of mercury, $[3\cdot99781] \times p \div \theta^{\frac{7}{3}} = p \div [\bar{4}\cdot00219]\, \theta^{\frac{7}{3}}$; the latter form is more convenient for calculation. The modified equation is therefore, for millimètres of mercury, Log p $= p_1 \div [\bar{4}\cdot00219]\, \theta^{\frac{7}{3}} + 25\cdot3379 - [0\cdot74625] \log \theta - [3\cdot48164] \frac{1}{\theta}$. For pounds per square inch, Log $p = p_1 \div [\bar{6}\cdot28859]\, \theta^{\frac{7}{3}} + 23\cdot62419 - [0\cdot74625] \log \theta - [3\cdot48164] \frac{1}{\theta}$.

For p_1 any trial number may be assumed, the nearer to p the better. If p comes out very different from p_1, apply the corrections for the difference to the first term, and find the result. For example, for $\theta = 473°$ the pressure is 11,662 mm. of mercury; but supposing we did not know it nearer than to guess that it would be about 8,000, and that we wrote this number for p_1. The sum of the terms after the first would be found to be $4\cdot01636$, and the common logarithm of the denominator in the first term would be found to be $5\cdot36420$; and the successive results would be 11,245, 11,614, 11,657, 11,662. If it is desired to compare the theta-phi pressures with those given in any table of steam pressures, the formula may be worked out by using the pressure given in that table for the trial pressure p_1, and the first result obtained will be practically the accurate theta-phi pressure.

The foregoing formula for finding the pressure applies only above the temperature 273°. At that temperature there is a step in the A curve. A corresponding deviation occurs in the G curve below 273°. Our knowledge of the relations of specific heat below

273° is imperfect; the author has therefore been contented to adopt the round number 0·5 as the constant specific heat of ice. The latent heat of liquefaction, according to the best authorities, is a little less than 80 units of heat; therefore 80·8 is what has been taken for it in the new units.

At the temperature of 273° the value of FG is only 0·000034; and as 0·001 makes less than one per cent. difference in the pressure, FG is omitted altogether in the formula for ice-steam pressures. In compression along a temperature line the shift horizontally or in entropy is $\frac{2}{m}\frac{dp}{p}$. For small differences this is at the rate of $\frac{2}{m} =$ 0·11136 for 100 per cent. of increase of pressure. The modified formula for the pressure of ice-steam is $\text{Log}\ p = 13{\cdot}35517 - [3{\cdot}4476028 - \log \theta] - \log \theta$. As before, the bracketed term is the common logarithm of the numerical value of the term.

The whole of Regnault's experiments have been calculated by the author according to these formulæ. The results are given in Table 11, and are also shown graphically in Figs. 21 and 22, Plates 83 and 84. The agreement with the experiments is closer than that obtained by using Regnault's most accurate formulæ. In Figs. 21 and 22 are plotted the differences between the steam pressures obtained in Regnault's experiments and those obtained by the theta-phi calculation. These are set off at the respective temperatures from the straight line marked $\theta\phi$, each position being denoted by a small cross. The scale for these differences in Fig. 21 is one inch = one millimètre of mercury; and in Fig. 22 one inch = the difference of pressure due to one degree difference of temperature. The curve RR shows the run of Regnault's calculated pressures, according to his final tables. The scope of error in the experiments can be estimated from the breadth over which the plotted differences are distributed. Excepting four outsiders which occur in his preliminary series *n* and *o*, every experiment recorded by Regnault is plotted in these diagrams. In Fig. 21, besides the curve R, there are curves marked F, C, and T. The curve F extending from −28° to −1° corresponds with a former formula employed by Regnault, according to which he generally gives the calculated pressures in stating the experiments on ice-steam. The

TABLE 11.—*Regnault's Experiments on Steam Pressure.*

(*Continued to page* 445.)

See Plate 83.	Pressure in millimètres of mercury.		
Temperature centigrade.	Regnault's Experiments.	$\theta\ \phi$ Calculation.	Regnault's Formula.
−32·84	0·27	0·20	0·29
−32·52	0·28	0·21	0·30
−30·59	0·33	0·26	0·36
−30·34	0·33	0·26	0·37
−28·45	0·38	0·32	0·45
−28·39	0·43	0·32	0·45
−28·13	0·47	0·33	0·46
−28·00	0·41	0·34	0·46
−27·80	0·48	0·34	0·47
−27·11	0·46	0·37	0·50
−25·31	0·52	0·44	0·59
−25·00	0·52	0·46	0·60
−23·95	0·53	0·51	0·66
−23·36	0·61	0·54	0·70
−22·74	0·71	0·57	0·74
−22·18	0·66	0·60	0·77
−21·79	0·71	0·63	0·80
−21·16	0·73	0·67	0·84
−20·38	0·74	0·72	0·90
−19·41	0·88	0·79	0·96
−18·69	0·93	0·85	1·03
−18·68	0·90	0·85	1·03
−18·41	0·98	0·87	1·06
−17·30	1·02	0·97	1·16
−16·83	1·16	1·01	1·21
−16·43	1·17	1·05	1·25
−16·15	1·15	1·08	1·27
−14·62	1·38	1·24	1·45
−14·31	1·38	1·28	1·48
−13·25	1·51	1·42	1·61
−12·55	1·62	1·50	1·72
−12·42	1·62	1·52	1·72
−11·69	1·70	1·63	1·84
−10·69	1·88	1·78	1·96
−10·55	1·98	1·80	2·00
−10·30	1·99	1·85	2·04
−8·11	2·39	2·24	2·43
−7·82	2·46	2·30	2·49
−7·85	2·51	2·31	2·50
−7·78	2·40	2·31	2·50
−7·57	2·49	2·35	2·54
−6·33	2·83	2·62	2·80
−5·54	2·94	2·81	2·99
−5·40	2·96	2·84	3·02
−4·85	3·20	2·98	3·15
−4·61	3·19	3·04	3·21

TABLE 11.—*Regnault's Experiments on Steam Pressure.*

(*Continued to page* 445.)

See Plate 83.	Pressure in millimètres of mercury.		
Temperature centigrade.	Regnault's Experiments.	θ ϕ Calculation.	Regnault's Formula.
−3·73	3·39	3·28	3·44
−3·71	3·41	3·28	3·45
−3·58	3·49	3·33	3·48
−2·43	3·81	3·67	3·81
−2·26	3·85	3·71	3·87
−0·37	4·48	4·35	4·48
−0·83	4·34	4·20	4·32
0·00	4·59	4·49	4·60
2·34	5·35	5·32	5·43
3·84	5·96	5·92	6·03
5·98	6·91	6·88	6·99
7·61	7·64	7·70	7·81
7·96	7·88	7·89	7·99
9·70	8·87	8·88	8·90
9·73	9·04	8·91	9·01
9·93	8·94	9·02	9·12
11·63	10·23	10·11	10·20
12·54	10·72	10·75	10·84
14·37	12·25	12·11	12·20
15·63	13·15	13·15	13·23
16·42	13·62	13·83	13·91
18·96	16·27	16·25	16·31
19·35	16·72	16·66	16·72
20·16	17·63	17·52	17·57
21·37	18·79	18·88	18·93
21·41	18·63	18·93	18·96
23·66	21·76	21·71	21·74
24·36	22·64	22·67	22·67
25·69	24·52	24·53	24·54
26·02	25·07	25·02	25·01
26·76	26·21	26·14	26·14
27·09	26·66	26·66	26·65
28·21	28·50	28·46	28·45
28·27	28·61	28·58	28·56
28·80	29·45	29·48	29·44
31·95	35·28	35·27	35·26
33·70	38·89	39·00	38·92
34·76	41·26	41·37	41·29
35·13	42·32	42·24	42·17
35·87	43·88	44·01	43·89
36·17	44·64	44·74	44·62
36·58	45·76	45·77	45·65
37·06	46·85	46·98	46·86
38·09	49·55	49·69	49·54
40·28	55·70	55·91	55·70
41·03	58·00	58·18	57·99

TABLE 11.—*Regnault's Experiments on Steam Pressure.*

(*Continued to page* 445.)

See Plates 83 and 84. Temperature centigrade.	Pressure in millimètres of mercury. Regnault's Experiments.	$\theta\ \phi$ Calculation.	Regnault's Formula.
42·86	64·13	64·11	63·90
43·65	66·61	66·78	66·57
44·08	68·18	68·30	68·08
44·38	69·28	69·39	69·17
46·22	75·87	76·28	76·04
47·00	79·61	79·39	79·11
47·16	80·19	80·01	79·74
48·99	87·57	87·76	87·44
48·97	87·59	87·65	87·36
48·99	87·55	87·78	87·45
49·58	90·06	90·39	90·10
51·21	97·40	98·03	97·71
52·32	103·80	103·53	103·15
53·49	109·61	109·55	109·22
53·61	109·90	110·19	109·88
56·81	128·46	128·51	128·13
60·87	155·25	155·38	154·91
62·04	163·44	163·93	163·47
62·64	168·62	168·52	168·05
65·86	194·62	194·75	194·30
70·44	238·20	238·12	237·58
71·44	248·17	248·63	248·04
71·76	251·75	252·04	251·49
75·25	292·21	292·14	291·59
76·47	306·53	307·36	306·83
78·95	340·30	340·39	339·79
79·50	348·16	348·10	347·50
80·11	356·00	356·88	356·28
82·80	397·44	397·50	396·93
83·06	401·30	401·63	401·06
83·06	401·29	401·68	401·15
84·15	419·66	419·28	418·76
84·90	432·29	431·82	431·34
86·66	462·30	462·56	462·18
87·47	476 46	477·44	477·01
89·74	519·58	520·72	520·47
89·83	522·02	529·47	522·10
90·68	539·51	539·63	539·20
91·30	550·26	552·26	551·79
92·18	569·79	571·03	570·73
92·39	573·97	575·42	575·12
93·65	604·08	603·09	602·87
93·57	601·98	603·26	603·07
94·02	610·54	611·44	611·31
94·85	628·70	630·52	630·28

TABLE 11.—*Regnault's Experiments on Steam Pressure.*
(*Concluded from page* 442.)

See Plate 84.	Pressure in millimètres of mercury.		
Temperature centigrade.	Regnault's Experiments.	$\theta\ \phi$ Calculation.	Regnault's Formula.
95·74	651·43	651·52	651·43
95·81	653·04	653·01	652·75
96·76	676·22	676·16	676·08
96·84	677·91	678·24	678·16
98·73	727·13	726·14	726·11
100·00	760·00	760·00	760·00
105·07	904·59	907·93	908·54
111·66	1131·47	1135·5	1136·9
122·48	1601·2	1608·6	1612·6
125·70	1779·1	1777·3	1782·6
128·45	1927·8	1932·1	1938·1
134·51	2316·1	2312·8	2320·4
138·98	2626·3	2630·1	2640·0
145·26	3127·0	3135·0	3147·0
150·00	3557·2	3565·6	3581·2
153·90	3944·6	3954·1	3972·4
157·32	4308·9	4322·1	4343·7
160·60	4704·7	4700·6	4723·0
161·16	4757·48	4767·0	4790·8
163·83	5089·0	5098·5	5123·9
166·99	5505·9	5511·8	5540·7
167·40	5554·8	5569·6	5596·4
175·63	6765·2	6787·6	6818·8
179·57	7459·1	7440·5	7472·5
180·23	7561·2	7553·0	7586·6
182·99	8090·0	8044·7	8079·0
185·65	8569·5	8543·1	8577·7
186·33	8664·3	8672·8	8708·0
189·07	9206·7	9225·5	9259·8
192·81	10004·0	10001·0	10035·0
194·46	10356·0	10368·0	10399·0
203·31	12433·0	12495·0	12516·0
208·27	13794·0	13828·0	13839·0
212·19	14861·0	14957·0	14958·0
214·79	15770·0	15780·0	15737·0
216·78	16259·0	16375·0	16354·0
217·08	16352·0	16470·0	16448·0
217·79	16644·0	16700·0	16674·0
219·93	17346·0	17402·0	17367·0
220·13	17360·0	17470·0	17434·0
221·36	17803·0	17885·0	17844·0
222·40	18222·0	18247·0	18195·0
226·85	19760·0	19845·0	19759·0
227·03	19807·0	19912·0	19825·0
230·53	21137·0	21246·0	21126·0

curve C, for ice-steam, shows what difference would be obtained if the same $\theta\,\phi$ formula were used as for water-steam. The curve T shows what is the variation for one-tenth of one degree. Bearing in mind what is the scale for each diagram, any one can easily appreciate what is the degree of corroboration afforded by these experiments.

The formulæ constructed by Regnault for steam pressures are intended to represent his experimental results only, and they are therefore not valid beyond the range of temperatures and pressures observed in the experiments. The method of calculation now presented has been arrived at by definite reasoning upon simple fundamental principles. These principles are not novel; the first has long been established in chemistry, and the second has long been accepted as applicable to perfect gas. There has also been a very general prevision of physicists in the direction of a wider application of these principles. In this paper the author has shown in detail the general method according to which they can be applied to every change of aggregation of matter. So far as Regnault's experiments on steam can be considered a good test of the soundness of the method, it can be said that there is most accurate confirmation. It will therefore be interesting to give here some examples of steam pressures calculated for the higher temperatures by the $\theta\,\phi$ formula, which however is valid only over that range of temperatures for which the conditions hold good that the heat of segregation is constant and F is identical with F_1.

The critical temperature occurs when the vertical ordinate of the W curve for actual water in Fig. 12, Plate 80, has swept over an area equal to the heat of segregation; that is, when that area to the right of the intersection with the gasene curve B in the theta-phi diagram, Fig. 24, Plate 86, is equal to the area between A and W; that is also, when the W curve and the entropy curve E meet. M. Cagniard-Latour found the critical temperature to be about the temperature of melting zinc, say 415° C. or 688° absolute. The formula for FG will therefore cease to be applicable beyond that temperature. As it is not known within a few degrees what the critical temperature really is, Table 12 is carried up to $\theta=700°$,

TABLE 12.—*Steam Pressures up to Critical Temperature, calculated by θ φ formula.*

Temperatures.		$\frac{2}{m} z$	Pressures.		
t	θ	FG	Pounds per sq. inch.	Millimètres of mercury.	Kilogrammes per sq. mètre.
Centig.	Centig.		Lbs.	mm.	kg.
230	503	0·01881	406·9	21042	286090
240	513	0·02102	488·9	25282	343740
250	523	0·02338	579·9	29988	407720
260	533	0·02687	691·6	35764	486240
280	553	0·03118	940·0	48613	660940
300	573	0·03695	1261·8	65250	887140
320	593	0·04315	1661·9	85939	1168400
340	613	0·05000	2156·2	111504	1516000
360	633	0·05665	2742·5	141820	1928200
380	653	0·06385	3448·1	178310	2424400
400	673	0·07180	4300·2	222275	3022100
415	688	0·07747	5017·1	259450	3527450
427	700	0·08226	5659·9	292690	3979350

that is 12° above the temperature of melting zinc. These pressures are higher than those obtained by Regnault's formula, which gives at 415° C. the following:—

t Centig.	θ Centig.	Pounds per square inch.	Millimètres of mercury.	Kilogrammes per square mètre.
415°	688°	4,067·1	210,321	2,859,510

Of course the formula was not given for pressures greater than one-tenth of the above.

That portion of the theta-phi diagram which includes the area upon which the steam engine works is shown in Fig. 24, Plate 86.

The gross pressures in pounds per square inch at any temperature are given numerically upon two curves which cross the diagram near the top; the pressure of the atmosphere is included. The auxiliary curve H is drawn according to $\text{A H} = \frac{2}{m} \frac{\theta}{p} \frac{d p}{d \theta} = \text{AE} \div x$. In this expression p is the pressure of saturated steam, and H is where E would be if the volume of saturated steam were that due to the temperature, for gasene of the same pressure. The β curve, shown also in Fig. 25, Plate 87, is used along with the H curve; it is drawn as follows:—from A at any temperature draw a vertical line down to Z in the base line, the absolute zero of temperature; and draw an oblique straight line from that Z point up to H at the same temperature; do the same for a number of temperatures, thus obtaining a number of oblique lines; β is then drawn touching these oblique lines. Any oblique line H β drawn down from any temperature on H cuts any entropy line for steam-at-the-same-temperature at a temperature proportionate to the $p\,v$ for the state-point of that entropy line. For example, in Fig. 24 the entropy line c Z is drawn for saturated steam at temperature 440°. An oblique line H β would cut c Z at 408°. The $p\,v$ of steam at 440° absolute is therefore less than the $p\,v$ due to gasene at 440° in the same proportion that 408 is less than 440. This proportionate temperature is denoted by the symbol β; and as $1{,}386 \frac{2}{m} = 1{,}386 \times 0 \cdot 11136 = 154 \cdot 345$, we get the rule $154\frac{1}{3}\,\beta = p\,v$ in foot-pounds. When the graph is one relating to moist steam, or when there is initial condensation, the β curve is very convenient, as β can be read off by merely laying a straight-edge from H to the β curve. When constructing adiabatic curves, the multiplication by $154\frac{1}{3}$ is avoided by working in thermodynamic units, instead of in foot-pounds: that is, working with the heat unit = 1,386 foot-pounds (page 400).

Upon Fig. 24, Plate 86, the dotted lines exhibit the order in which ergation, or change of heat into mechanical work, proceeds in a perfect steam engine. In the example given, the gross steam pressure is 106 lbs. per square inch; it is expanded until the pressure falls to 10 lbs., and it is then exhausted against a

back pressure of 3 lbs. per square inch. The feed water is supplied at 333° absolute. From temperature 333°, denoted by letter m on the primary curve A, draw a vertical line mZ down to the base line, the absolute zero of temperature. The area to the left of this vertical line represents the energy already possessed by the feed water at that temperature. Through 106 lbs. on the pressure curve draw a horizontal line $a\ c$ from A to E; $a\ c$ is seen to be at temperature 440° absolute. The intersection of this line with the intropy curve I is lettered b. By intropy is meant the same as entropy, only that, while entropy includes the energy of the $p\ v$ of the substance, this energy is excluded from intropy. The initial letters E and I, being the same as for external and internal, serve to distinguish the meanings. The intropy curve I marks off at any temperature what heat or energy is *possessed* by saturated steam. At any temperature $\mathrm{I\,E} = \frac{2}{m} - \mathrm{FG}$, and $\mathrm{B\,I} = \frac{5}{m} - \frac{5}{2}\mathrm{FG}$. The area θ.I E is the $p\ v$ of the steam; it is work already done, and it is therefore no longer energy possessed by the steam. Draw verticals to the base line through b and c. The $p\ v$ of one pound weight of steam at 440° is denoted by the area $\theta.b\,c$. Through 10 lbs. on the pressure curve draw the horizontal temperature line $d\,h$, that is at temperature 363°. Measure β for 363° on c Z, and set off $f\,h$ = one-ninth of $\beta \div 363$. Strictly it is $0{\cdot}11136\,\beta \div 363$; but if the molecular weight of water is taken, as it usually is, as = 18, then $\frac{2}{m} = \frac{1}{9}$; and then also we have $p\ v = 154\,\beta$. Draw the vertical f Z, and set off on any scale $h\ k$ = 10 lbs. the terminal pressure, and $k\,l$ = 3 lbs. the back pressure; and draw a vertical g Z through l. The ergation, or change of heat into mechanical energy, is the horizontal band $a\,c\,h\,d$ plus the vertical rectangle $f\,h$ Z Z. The loss by back pressure is the vertical rectangle $f\,g$ Z Z. When the steam was admitted, the work done was $b\,c$ Z Z; during expansion the intropy point travelled from b down to f; and if we suppose the right-angled corner of a set-square to move downwards with the intropy point while the edges are horizontal and vertical, the ergation would be the area uncovered by the top or horizontal edge less the area covered by the vertical edge.

The author has called the latter area the "slip" of expansion. Forgetting the slip is a common mistake. The area uncovered by the top or horizontal edge of the set-square as it travels downwards is the work due to the heat of the liquefaction going on. The slip is the $p\,dv$ of the "collapse" in this liquefaction. The ratio of volume to initial volume at any instant is $\beta_2\, p_1 : \beta_1\, p_2$, where p_1 and p_2 are the pressures, and β_1 and β_2 the corresponding proportionate temperatures as described above. When an engine is conditioned to a certain ratio of expansion and a certain initial pressure and a certain back pressure, say those assumed in this example, the perfection duty of such an engine is represented by the area $a\,c\,Z\,Z\,g\,d$ per pound of steam supplied; and any fraction which may be realised of this duty is the efficiency of the engine in relation to perfection.

The work, and the heat or energy, being both always represented by their appropriate areas on the theta-phi diagram, the non-mathematical engineer is thereby enabled to see exactly what the thermodynamical relations and possibilities are in any problem about steam, without employing any complicated mathematical expressions which are likely to be misunderstood by him. Perceiving this advantage, the author has therefore persevered in trying to overcome the difficulty there was in making one diagram-field continuous for moist steam and for superheated steam; and this he has now accomplished by showing that, according to Regnault's experiments, saturated steam up to at least 400 pounds pressure on the square inch possesses the total heat of segregation at all temperatures, and by demonstrating how the $p\,v$ of steam varies from the $p\,v$ of gasene. This paper, he regrets, is not written attractively, and it must be uninteresting to the greater number of those who hear it read. Those who grasp the meaning of the investigation, and realise what an extension it gives to the definite application of the Carnot-Clausius Second Law, will, it is thought, agree with the author that, if the conclusions he has arrived at are well founded, the time he has devoted to the study has not been misspent.

Discussion.

The President said there was one point in the paper (page 406) which concerned all engineers intimately, and on which special stress had been laid, namely the ratio of the specific heat of air at constant volume to its specific heat at constant pressure, as deduced in so remarkable a manner from the velocity of sound. Having been much struck by that portion of the paper, he had taken 12·387 cubic feet as the volume of one pound weight of air at 32° Fahr. under a barometer pressure of 760 millimètres, which was equal to 14·7 lbs. per square inch.* Arranging the pound of air in a column 1 foot square, the height of the column would be 12·387 feet; and raising its temperature one degree, its volume would be expanded 1–493rd, and the height of the column would be increased 0·025 foot, that is from 12·387 to 12·412 feet. The pressure on the top of the column being 14·7 lbs. per square inch, and its area 144 square inches, the work so done would be $14·7 \times 144 \times 0·025 = 53$ ft.-lbs.; and taking 772 ft.-lbs. as equivalent to one unit of heat, or the heat required to raise 1 lb. of water through 1° Fahr., the 53 ft.-lbs. represented 0·069 unit of heat. Now the specific heat of air at constant pressure, as determined by Regnault's experiments, was 0·238; that is to say, the whole quantity of heat expended in raising the temperature of the 1 lb. of air through 1° was 0·238 unit of heat. But this included the work done in expanding its volume, which represented 0·069 unit of heat; and hence the specific heat at constant volume was $0·238 - 0·069 = 0·169$. The ratio of the specific heat at constant pressure to that at constant volume was therefore $0·238 \div 0·169 = 1·408$.

Carrying on the same idea to the transmission of sound, a column of air of 18,454 feet height was required for discharging into a vacuum with the velocity of 1,090 feet per second, which was that necessary for transmitting sound by vibration, according to the observations of Arago, Prony, Humboldt, and others. Such a velocity thus required

* See "A Practical Treatise on Heat," by Thomas Box, 4th edition 1883, pages 6 to 9.

(The President.)

a height more than eighteen times that of the Eiffel tower. But Sir Isaac Newton by independent calculation had previously come to the conclusion that the velocity necessary for the transmission of sound was only 917 feet per second, which corresponded with a height of air column of only 13,110 feet. To Laplace was due the suggestion that from this lower height had been omitted altogether the work done in compressing the air with the force necessary to produce the waves of sound; and he had suspected that the difference between those two heights of 18,454 feet and 13,110 feet might represent the work done in the compression, whether by the discharge of a cannon, or by the sound of the voice, or by a flash of lightning, displacing the air and creating its movement, and not only doing this work but absorbing heat in doing it. Dividing the 18,454 feet by the 13,110 feet, Laplace's hypothesis was verified, the quotient being 1·408, which represented the ratio of the specific heat of air at constant pressure to its specific heat at constant volume.

Professor Ryan said he had accompanied the author on the previous day to the Collége de France, and had endeavoured to assist him by making certain observations which he wished to put on record at this meeting. The observations had reference to page 401 of the paper, in which the author surmised that there had been an error in the recording of the numbers observed by Regnault. In Table 1, given on pages 402 and 403, the numbers contained in the middle column E showed the difference between those in columns C and D. Commencing with 42·2 grammes, it would be seen that the numbers in column E consisted usually of two figures before the decimal point, but there were occasionally three figures; and in the case of the last seven in particular the figures were very high, beginning with 447·8 grammes in No. 34 and ending with 397·6 in No. 40. The author imagined that these seven numbers were wrong, because they differed so much from the others. So far as he understood, these numbers were not furnished in Regnault's researches, but were here calculated by the author from the numbers furnished by Regnault. The total weight of water involved in Regnault's determination of the specific heat of water was given in column C,

and its excess above the capacity of the calorimeter up to the zero line was given in column E: this excess being an additional weight of water, which, owing to the exigencies of the experiments, was left in the gauge-glass at the top of the calorimeter wherein the experiments were made. The water in the calorimeter stood in one experiment at one height in the gauge-glass, and in another at another height, in accordance with the differences $C-D$, which were given in column E. The author thought that Regnault had got the weights of the water correct, and that his conclusions were correct; but that the numbers given in his report had been furnished probably by some assistant, who had perhaps not been familiar with the exact experiments and had made some errors in calculation. Particularly the author suggested, in page 401, that the difference in the sign of π in the formula there quoted from page 739 of Regnault's report might account for the discrepancy. The interesting point therefore was to see whether or not the actual gauge-glass would really hold so much water as was shown in column E of Table 1.

On going to the College they had discovered after some difficulty the particular vessel that had been used. Regnault's apparatus was carefully preserved there, and any portion of it could be seen: which was a great boon to scientific men of all nationalities, who might wish to examine it. But the particular vessel they had been in search of was one which was not included in that classic collection; and they had had to hunt about to try and discover it. Many vessels were submitted to their inspection before they found the actual one; and when they did find it, they saw that it had been subjected to alterations. The others had been carefully preserved, but this particular vessel had been altered, possibly by Regnault himself, or possibly by some successor. There was great difficulty in identifying it, but they had succeeded in doing so completely, so that he had no doubt it was the correct one, the chief dimensions corresponding exactly with the picture given by Regnault. It was a cylinder with two conical ends; the openings, such as remained, corresponded with those in the depicted vessel, while the places could be seen where pieces of zinc had been put on to cover up the missing apertures. The opening at the top

(Professor Ryan.)
of the vessel was the one with which they were concerned; it was a tubular nozzle, on which had been placed the gauge-glass containing the excess water whose weight and volume were in question. On taking the measurements from the actual drawing given by Regnault, they found that the gauge-glass would not contain more than 400 grammes of water if filled to the top, without making allowance for the stirring rod, and for the fact that the experimenter in stirring would shake the water and throw some over the sides if the glass were filled quite full. A careful man like Regnault would therefore not have allowed it to be filled to the brim. As 400 grammes of water appeared to be the utmost that could be contained in the vessel, the author's conclusion (page 404) that 447 was erroneous was borne out by the published diagram. But when they got the actual vessel itself and made measurements of it, they found that the possibilities were even more restricted than appeared from the drawing. In the latter the outside diameter of the gauge-glass was 5·92 centimètres, and the inside diameter would come to something like 5·47 centimètres, while the height was given in the drawing as 16·84 centimètres; roughly therefore 396 grammes was the utmost weight of water that might be contained in it. But taking the actual vessel, the internal diameter of the glass, which was slipped over the outside of the tubular nozzle, must have been about 3·8 centimètres; and the calculation with that diameter gave about 191 grammes as the extreme amount of water the glass could contain. In his researches Regnault had stated that the gauge-glass was graduated in divisions, each of which corresponded with 1·98 gramme of water. If therefore the glass was divided into a hundred parts, its whole capacity would be 198 grammes, instead of 191 as calculated by himself. At all events it was impossible that the sketch could be correct, because the sketch gave 5·92 centimètres outside diameter for the tubular nozzle, and the zinc vessel though altered could not have had a hole of that size filled up without the patch being distinctly visible. The zinc vessel was continuous all round the bottom of the existing tubular nozzle of 3·8 centimètres outside diameter; and therefore the original tubular nozzle might have been less than 3·8 centimètres in diameter, but could not possibly have been more.

Hence the extreme weight of water would be less than 200 grammes, and consequently all the numbers given in column E of Table 1 above that amount were certainly too large. The importance of this conclusion he would leave the author to point out. As a matter of fact the author believed that it did not affect Regnault's actual calculations.

The results set forth in the present paper appeared to be deduced from a basis laid down in a previous one read before another society; and while the present paper gave interesting practical conclusions, the previous one, so far as he could judge by description, seemed much more captivating. The author had concluded his present paper with the expression of an opinion in respect of which he thought all would sympathize with him, as it was almost impossible to write a paper full of mathematical symbols in an attractive manner; but the earlier paper he thought would be freer from this objection. He looked forward to seeing the preliminary calculations in the earlier paper, as the value of all the rest would depend on them; while without them it would be almost impossible to come to a conclusion with regard to the true value of the present contribution. But whether the author was right or wrong, he would have done good service to science in general by bringing these matters forward. He was showing engineers that they need not for ever consent to remain in ignorance, and to regard the phenomena and operations of steam as something mysterious and incomprehensible. Those phenomena must depend on certain elementary mechanical principles in nature; and some such elementary principles were clear in the mind of the author, if they were not yet clear to others. He was therefore rendering service to science in laying open the workings of his own mind, in order that others might estimate the value of his conclusions, to correct him where he was wrong, and appreciate him where he was right. He was indeed following in the steps of Newton, because it was Newton who had first suggested the theory that universal gravitation might be due to a gravitating ether surrounding all bodies. For himself he was certainly charmed by the way in which the author, whether rightly or wrongly, had evolved from that simple Newtonian hypothesis the different

(Professor Ryan.)
phenomena of the forces of nature—gravitation, chemical affinity, cohesion, and others. It was an interesting study, even if it was not at present entirely satisfactory. He might recall the fact that Rankine himself had started with a mechanical hypothesis of a somewhat similar kind—not similar in details, but similar in its general character—in his attempt to evolve the phenomena of thermodynamics from elementary mechanical principles. It was true he had afterwards abandoned that attempt, and had fallen back on elementary laws, such as the second law of thermodynamics; and his effort had therefore to a certain extent failed. Whether or not the author would succeed in converting the present generation of physical investigators to his methods of deducing familiar consequences, no one could foretell.

The only criticism which he was inclined to offer at the moment with regard to the present paper was that it had the appearance of setting forth in page 413 a new second law of thermodynamics. Already a good many second laws had been promulgated, and the present paper seemed to be adding to the number. He knew the author differed from him on that point and would show good cause. As expressed by Clausius the law appeared to him to be the simple elementary statement that heat could not of itself without compensation pass from a cold body to a hot body; no mathematical quantitative statement was necessary, but a simple elementary principle had to be presumed, from which all the rest might be derived. A law of nature he regarded as something more than a mere collocation of facts, such as was implied in a curve which was merely the locus of "characteristic state-points"; it was something which should involve those mathematical deductions, in so far as they might be shown to follow from the law.

To the lucid explanation given by the President of the importance of the ratio of the two specific heats of air, he might be permitted to add a word. He had shown why the velocity of sound as calculated by Newton was inaccurate. The elasticity of the air was altered by the heat changes, in the way the President had shown: the heat developed in the condensation increasing the elasticity of the air, while that absorbed in the rarefaction diminished it. The

result was that the sound travelled more quickly than it otherwise would do; for, as Professor Tyndall had pictured it, the spring behind the particles of air might be imagined to be stiffened and the spring in front to be slackened.

Professor ALEXANDER B. W. KENNEDY, Member of Council, wished, as far as he could, to express his recognition of the value of the sort of work on which the author had so long been engaged, and of the importance of the direction in which he was now leading them. If he rightly understood the present paper from the steam-engine point of view, which was the point of view whence he regarded it, the author's results might be summed up somewhat as follows:—that having adopted a certain molecular hypothesis, or a mechanical hypothesis as Professor Ryan had called it (page 456), he believed he could substitute certain thermodynamic expressions in place of the empirical equations received from Regnault, which had hitherto been used for expressing the relation of temperature to pressure in steam, or the total quantity of heat possessed by steam. Those substituted expressions were given in various parts of the paper, and they would be seen to be really thermodynamic expressions, that is, based upon physical laws, and not containing in the same way as former equations had contained the merely empirical quantities deduced from experiment. This was of course a result of the highest importance, for the sake of obtaining which Members might well be glad to see in the Proceedings a paper containing a larger amount of differential and integral calculus than usually appeared therein. It would be presumptuous on his part to attempt to criticize the paper at all, because he had not been able to attend the meeting of the Naval Architects at which the author's original paper had been read, and as that paper had not yet been published he had not had an opportunity of reading it. The author had very properly and candidly commenced the present paper with the conclusions he had arrived at in the former; and it was only right that the Members should recognize the great importance of the results which he appeared to have obtained. He used the expression that those results *appeared* to have been obtained, not as throwing the slightest doubt

(Professor A. B. W. Kennedy.)
upon them, but because he had not been able himself to go through the processes by which they had been obtained.

In regard to the theta-phi diagram, about which he had heard for a great many years, he believed that one of his university colleagues had received it from the author many years ago, and had been teaching it ever since. It had been partly published recently in the Proceedings of the Institution of Civil Engineers (1888, vol. xciii, page 134); and he was so charmed with it that he should put it to all the uses he could, which he expected would be a great many. He should be further helped in this respect if the author would kindly give some examples of his own as to its use.

In the author's reply he should be glad if he would explain with regard to some of the complete expressions in the paper — such as that on page 418 for the relation of pressure and temperature of steam, and that on page 432 for the total quantity of heat in steam— to what extent the decimals might be thrown aside: because it was of course a tedious process to work with numbers containing seven significant figures. No doubt the author could state how many of those figures would sensibly affect the result, not from a physical but from a practical point of view.

If the author could only have used a few more of the expressions which were common among engineers, and a few less of the improved expressions introduced in the paper, he thought it would have been a good deal easier to follow him. His own greatest difficulty in understanding the work had been to get fully into his head the meaning of the several new expressions used. He was quite prepared to believe that they were improvements on the old ones, so far as he had seen; but he thought the author, who had had this difficult subject in his mind for so many years, hardly realised how much its difficulty was increased for others by the new expressions introduced. Most, though not all, of the single ideas which had here been brought together in so original a manner were more or less familiar, and there were more or less clumsy names for a great many of them; and it would therefore have been easier, if not so scientifically satisfactory, had the author found himself able to continue the use of the older names. This was not intended as

criticism on the matter of the paper, but only on its manner; and he was induced to offer it because of the difficulty he had himself felt in following the paper. He had heard it said that this Institution ought not to have a paper of such a theoretical kind in the Proceedings; for himself however he must hold another opinion. He was very glad that at one and the same meeting the Members were able to show themselves as mechanical engineers sufficiently catholic to accept with real honest gratitude a paper like the present, however difficult it might be to understand, for the sake of the originality of its treatment and the importance of its results: and to accept also a paper like Mr. Paget's, embodying in an almost ideal form the work of the mechanical engineer in the direction of mechanism. When they could thus consider in the course of one meeting gasene and aquene and the warp-weaver, he thought they showed that the mechanical engineer's work covered pretty much all that was worth doing in the whole range of applied mechanics.

Professor H. S. Hele Shaw felt that full justice had scarcely been done to the author, notwithstanding that the two previous speakers had each of them borne testimony to the nature and value of his work; but his work covered such a vast amount of ground that the author might naturally be desirous of having some sort of expression of approval from those who were supposed to have made a study of the more scientific part of it. Engineering professors might often have to hide their diminished heads on practical questions, and to admit that they knew little about the practical bearing of many subjects; but on other questions they might be expected to contribute whatever they might know. In reading the paper—like others, without getting to the bottom of it, for it would take a much longer time to do that than he had been able to devote to it—he had not been able to find a single statement to which he could take exception. The author's previous paper also he had during this meeting had the opportunity of reading; but it did not come into the present discussion, and therefore he would not allude to it further than to say that it was a paper of the greatest interest, and he only wished he had had it in his hands before.

(Professor H. S. Hele Shaw.)

As Professor Kennedy had remarked (page 457), the practical importance of the present paper lay in the fact that it attempted to calculate, and as a matter of fact did calculate, upon first principles those results which had hitherto been arrived at by empirical formulæ, namely the results obtained experimentally by Regnault, who had merely attempted to find some expression which would fit them. Those who were accustomed to teach the subject of thermodynamics had to construct curves of the action of the steam engine under all sorts of conditions; such curves had first been elaborated by Professor Cotterill in his work on the steam engine, and were regularly drawn at the Royal Naval College at Greenwich, and elsewhere. It was simply necessary to take the tables of Regnault as they stood, and to depend entirely upon these for plotting the curves. But the author had now shown how, instead of having recourse to large tables which it was not always possible to obtain, formulæ might be used for arriving at the same results. If he could simplify the formulæ still further, every one would be grateful to him. The long and complete Table 11 in pages 442 to 445 depended upon the formula given in page 440, which no one could easily carry in his head; and if it could be simplified it would be a great advantage. The most valuable feature of the paper was the theta-phi diagram, wherein the curve AA was the one on which the author laid so much stress. In dealing with the energy of steam, it had hitherto been necessary to integrate, by mechanical means known to every engineer, a curve representing the pressure in relation to the volume, in order to find the area of what the author called the $p\ v$ diagram. The theta-phi diagram he had not before seen drawn; and although in Clerk Maxwell's work on thermodynamics and elsewhere the two elements from which this diagram was constructed were dealt with together, still he had only now for the first time seen them thus combined in a most interesting and he believed a practically valuable manner. The point on which stress was rightly laid in this diagram was the use that engineers might be able to make of it for practical purposes; for by means of the curves here drawn the energy of the steam could be determined as a simple matter of measurement without calculation, instead of

having to calculate an area from a number of measurements of curves.

Mr. JEREMIAH HEAD, Past-President, considered that questions such as those involved in the present paper came especially within the province of such Members as the three professors who had just spoken. He regarded them as the legislators or lawgivers of the engineering profession. The business of the bulk of the Members was more analogous to that of the administrators of the law. It was seldom that the two functions were found combined in the same person. But engineers in general were none the less grateful to men like the author, who ascertained the laws of nature which they could afterwards apply for themselves; and he had seen enough of the paper to be quite sure that it was an exceedingly valuable one. It came also most opportunely at the present time, when so much attention was being given to getting more work in the shape of power out of the fuel burnt. It was rather a sad thing to reflect upon that, out of the total heat capable of being developed from the coal burnt, not much more than half was utilised in the boiler, and not much more than ten per cent. in the final work done. This showed that there was still great room for saving; and it was the bounden duty of engineers, with the help of men like the author, to give all the attention they possibly could to the subject, so that they might not waste the fuel resources of their own and other countries; because when once the world had used up its fuel he did not know what would become of engineering.

Mr. ARTHUR PAGET, Vice-President, wished to call attention to the opinion expressed by Professor Ryan (page 455) that it was very difficult to come to a conclusion with regard to the true value of the present paper, in the absence of the author's earlier paper read to the Institution of Naval Architects on 11th April last. Professor Kennedy had followed with a remark to much the same effect; while Professor Shaw, who had enjoyed the advantage of reading the earlier paper, though after the present one, had expressed the wish (page 459) that he had had it before. He therefore begged to propose

(Mr. Arthur Paget.)

that the author be asked to grant his permission, and to obtain the permission also of the Institution of Naval Architects, for the earlier paper, forming the theoretical foundation on which the structure of the present had been erected, to be published also in the Proceedings of the Institution of Mechanical Engineers. In the case of a paper of such importance, and one which so many of the Members found it difficult to understand, it appeared to him highly desirable that they should have the opportunity in their quiet moments of fully studying it, which they would not be able to do unless they had the other paper before them. They were not all members of the Institution of Naval Architects; and it might therefore be difficult for them otherwise to get the earlier paper for the purpose of referring to it in connection with the present one.

Mr. Head had much pleasure in seconding the motion proposed by Mr. Paget. The request seemed a reasonable one, and he had no doubt that both the author and the Institution of Naval Architects would gladly accede to it.

The President gathered from the applause with which the motion was received that no amendment would be proposed. He therefore put the motion to the meeting, and it was unanimously adopted.

Mr. J. Macfarlane Gray said he had no objection to the publication of the earlier paper in the Proceedings of this Institution; and the Institution of Naval Architects he was sure would have no objection. He had had a good deal of correspondence with the President about the ether pressure, and had been much gratified to find that he had taken so much interest in the matter. The President had asked for explanations of various matters which had not been made quite clear; and he desired to thank him for the pains he had now taken to help on the discussion by the remarks he had made. He thanked Professor Ryan for having accompanied him to the Collége de France to see Regnault's apparatus, and for having verified the statement made about the gauge-glass in the paper; Professor Ryan had shown that he was really as much taken up with

the subject as himself. He also thanked Professor Hele Shaw for the interest he had taken in the matter. In regard to his not having previously seen the theta-phi diagram for water, steam, and steam-gas, the diagram was new to himself in almost its present form in 1879, and as far as he then knew it was an original production. For two or three years before that date he had employed the same ordinates in his own studies; and he had since learnt that others had done the same for gas. The diagrams with the lines A B C G K and P, Plates 80 and 86, had been exhibited as a wall diagram when his 1880 paper was read before the Institution of Naval Architects. He had then been told that Professor J. Willard Gibbs of Connecticut had published the diagram some years before. On obtaining from America a copy of Professor Gibbs' paper he found it was entitled "Graphical Methods in the Thermodynamics of Fluids." It was contained in the Transactions of the Connecticut Academy of Arts and Sciences, Vol. II, Part 2, pages 309–342, date April 1873. The first paragraph of the paper very well explained its object:—"Although geometrical representations of propositions in the thermodynamics of fluids are in general use, and have done good service in disseminating clear notions in this science, yet they have by no means received the extension in respect to variety and generality of which they are capable. So far as regards a general graphical method, which can exhibit at once all the thermodynamic properties of a fluid concerned in reversible processes, and serve alike for the demonstration of general theorems and the numerical solution of particular problems, it is the general if not the universal practice to use diagrams in which the rectilinear co-ordinates represent volume and pressure. The object of this article is to call attention to certain diagrams of different construction, which afford graphical methods co-extensive in their applications with that in ordinary use, and preferable to it in many cases in respect of distinctness or of convenience." And in page 317:—"Such diagrams may of course be produced by an infinity of different methods, as there is no limit to the ways of deforming a plane figure without altering the magnitude of its elements. Among these methods, two are especially important,—the ordinary method in which the volume

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and pressure are represented by rectilinear co-ordinates, and that in which the entropy and temperature are so represented." The author then proceeded to show the advantages of the entropy-temperature method; but he drew (page 325) only one line of the theta-phi diagram given in the present paper, namely a portion of the A curve without distinguishing between aquene and water. Professor Gibbs' paper was a very high-class production, revelling in mathematics; and it showed that the advantages of the theta-phi system of ordinates were therefore well known to Professor Gibbs years before he had himself worked at it. He therefore did not claim novelty for the co-ordinates adopted: what he did claim was that he had done what others had only said could be done, namely determined and drawn for practical use by engineers the curves A, B, C, I, E, F, G, H, constituting the theta-phi diagram for water and steam, Plates 80 and 86. The originator of the system of entropy-temperature co-ordinates might however be said to be Sadi Carnot, a relative of the President of the French Republic, who in his essay, "Réflexions sur la puissance motrice du feu," had brought forward the analogy of the water-wheel to illustrate the action of heat, his idea being that the effect of heat in doing work in a heat engine was related to the heat expended in the same manner that the work done by water on a wheel was related to the whole height of the fall. The theta-phi diagram was merely the same idea represented graphically. About the time that he read Carnot's work, he had occasion to write something on the same subject, and he then gave the water-wheel illustration in the following form. If water on a water-wheel was to represent correctly and proportionately the efficiency of any heat engine, we might regard the source of power as the work of imps, provided by nature, who pumped all the water used on the wheel from a pit in which the level of the water was constantly 273 feet below the level of the sea. The wheels were on a plateau, whose drainage level was about 50 feet above the level of the sea. The imps pumped from the pit only, and never from the tail race. If we wished to apply the tail-race water, we must do the pumping by the wheels; the imps would not do that for us direct. The tail race was therefore more than 50 feet above the sea level. On

the theta-phi diagram, the 273 was the absolute temperature of melting ice, and the 50 was the temperature (above 273°) of a cool condenser of a steam engine; and all the heat applied was always put into the working substance the full height from the bottom of the pit, or absolute zero, up to the height of the temperature at which it was received, and there was no way of getting out of that waste of imp labour. The height at which the water was applied on the wheel was the temperature at which the working substance received the heat. The A curve on the diagram showed the different heights at which different portions of the water were applied on the wheel, or the different amounts of heating of the feed. The latent heat of evaporation was delivered on the wheel all at the same height, as denoted by the particular temperature line from A to E. It was in this way he had first been led to make the theta-phi diagram. The danger of this illustration was that the water pumped by the imps denoted heat, not water; and the water denoting heat, and the actual water to be heated, were likely to be confounded one with the other in the mind; and thereby it was also likely to be thought that to superheat steam would raise the efficiency of all the heat applied. This was not so, for only the heat which superheated had its efficiency increased according to the temperatures at which its respective portions were imparted to the working substance.

In regard to Professor Kennedy's enquiry (page 458) about doing away with some of the figures after the decimal points in the formulæ, his object had not been to make handier rules for steam pressure, but to discover why these pressures were so in nature, and how they were related to the laws of matter and motion. The experiments of Regnault had been taken as a reliable account of what these pressures were; and the results of the calculations given in the paper were practically identical with those experiments. The exact temperature at the high temperatures was not known with certainty within one-fourth of a degree; and the difference at the highest temperatures in Fig. 22, Plate 84, did not exceed that amount. In Fig. 21, Plate 83, the divergence seemed to be greater, but the scale was different; here each of the divisions represented the pressure of

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1-250th of an inch of a column of mercury. From 30° centigrade below freezing-point up to within 10° of boiling-point it would be seen that the pressures arrived at by the theta-phi calculation did not vary by one millimètre or 1–25th inch of mercury from the pressures obtained in Regnault's experiments. There was a great difficulty in ascertaining what was really the temperature; Regnault's experiments varied from one another as much as any of them varied from the theta-phi calculation. Professor Hele Shaw had spoken (page 460) of simplifying the formulæ for practical purposes. The complicated formulæ given in the paper were those required for the construction and verification of the permanent curves of the theta-phi diagram. For practical purposes the diagram would be procurable ready-made, and practical problems would be solved principally if not entirely by drawing a few straight lines on the ready-made diagram. He would give one example:—find the momentary value of the index n in $p^{n-1}\, v^{n}$ = constant, for any specified position in the expansion of steam, say at the termination of the expansion proper in the example given in Fig. 24, Plate 86, that is, for the entropy point h or intropy point f. Continue dh to the point H on the H curve, Fig. 25, Plate 87; and from the point H draw a tangent to the curve β, cutting hZ in S, the tangent point being R. From S set off downwards ST, equal to nine times $dh = 9 \times 1 \cdot 312 = 11 \cdot 808$ on any convenient scale. Join RT and continue to V on the vertical drawn downwards from the point H. Draw HW downwards as a tangent to the H curve at the point H. Draw VW parallel to RH. Draw the horizontal line WU cutting HV in U. The length of HU $= n = 8 \cdot 84$ on the same scale as was employed for ST.

In the theta-phi diagram for practical use the scale was fourfold that of Figs. 24 and 25, Plates 86 and 87. The numbers 0·1, 0·2, &c., on the 273 temperature line denoted entropy ϕ, measured from the A_{273} vertical; and all the calculations in the paper, namely those for OA, OB, OF, OG, OP, were worked out in terms of entropy as marked on this scale. The $\frac{2}{m}\,\epsilon \log \frac{p}{p_0}$ in the pressure formula (page 439) was FP measured on the same scale of entropy; and the FG column in Table 5 (page 430) was also according to the same scale. The numerical utility of entropy would be better appreciated

on working out the different calculations. In Table 13 were given the abscissæ or entropy values ϕ for the several curves A, B, E, F, G, H, P, in the theta-phi diagram, Fig. 24, Plate 86, corresponding with successive values of the absolute temperature θ from 273° up to 513° centig., by means of which these curves could be constructed. For practical use the three curves A, E, H, were alone necessary, for which the entropy numbers ϕ were given in the columns headed OA, OE, OH respectively in Table 13.

TABLE 13.—*Construction of Theta-phi Diagram, Fig. 24, Plate 86.*

Entropy values ϕ or abscissæ for curves A, B, E, F, G, H, P, corresponding with successive values of absolute temperature θ from 273° up to 513°.

$\theta°$ centig.	ϕ = OA	ϕ = OB	ϕ = OE	ϕ = OF	ϕ = OG	ϕ = OH	ϕ = OP
513°	0·63749	1·14208	1·45827	1·51082	1·53184	1·64925	2·47222
503°	0·61760	1·15232	1·47656	1·52336	1·54208	1·65013	2·46377
493°	0·59730	1·16336	1·49460	1·53640	1·55312	1·65313	2·45672
473°	0·55545	1·18818	1·53272	1·56502	1·57794	1·66098	2·44058
453°	0·51179	1·21707	1·57235	1·59712	1·60683	1·67528	2·42004
433°	0·46616	1·25070	1·61599	1·63347	1·64046	1·69302	2·40614
413°	0·41836	1·28983	1·66268	1·67476	1·67959	1·71911	2·38771
393°	0·36820	1·33545	1·71426	1·72208	1·72521	1·75317	2·36836
373°	0·31541	1·38870	1·77171	1·77653	1·77846	1·79737	2·34800
353°	0·25927	1·45109	1·83698	1·83974	1·84085	1·85280	2·32652
333°	0·20078	1·52140	1·91217	1·91359	1·91416	1·92095	2·30379
313°	0·13818	1·61095	1·99979	2·00045	2·00071	2·00119	2·27965
303°	0·10537	1·66010	2·04927	2·04969	2·04986	2·05222	2·26699
293°	0·07145	1·71373	2·10313	2·10339	2·10349	2·10501	2·25391
283°	0·03636	1·77238	2·16192	2·16208	2·16214	2·16312	2·24038
273°	0·00000	1·83663	2·22627	2·22636	2·22639	2·22658	2·22636

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What he had laid down in the theta-phi diagram did not differ from Professor Clerk Maxwell's conclusions. There was only one second law of thermodynamics, though it was expressed somewhat differently in the present paper (page 413) with a view to rendering it more acceptable for practical purposes.

The PRESIDENT was sure they all felt greatly indebted to Mr. Macfarlane Gray for his very able paper, though some might think it also very abstruse. There were points in it which might well form the subject of study in detail, and by which engineers might profit, hoping some day or other to be able to comprehend fully the ideas that were in the author's mind, which were far larger than he had set forth in the present paper. It was clear from the references made to his earlier paper that his grasp of physical laws was far greater than anything that had been brought forwards in the present paper in connection with the subject of steam. He trusted therefore they would have the privilege of publishing that earlier paper in their own Proceedings.* The author had cheerfully expressed his willingness; and it would be only courteous to the Institution of Naval Architects to ask their concurrence. He proposed a warm vote of thanks to Mr. Gray for having given in this paper the results of eighteen years of study.

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* See pages 379–394.

ON WARP WEAVING AND KNITTING, WITHOUT WEFT.

By Mr. ARTHUR PAGET, of Loughborough, Vice-President.

There are three chief methods or principles of making fabric or cloth or tissue from yarns or threads.

The method best known and most used is that of ordinary weaving with a "warp" and a "weft," the warp running longitudinally in the fabric and the weft transversely, as shown in Fig. 51, Plate 100.

The next best known and probably the next most used is "knitting" properly so called; that is, knitting together or weaving or interlacing a single thread of weft only, Fig. 52, as in hand-knitted goods such as stockings, socks, vests, drawers, and articles of underwear generally. In some machines more than one thread is used in knitting; and then it is as it were an interweaving or interlacing of "weft-threads," knitted to and fro across the length of the fabric, without any "warp-threads" running longitudinally.

The least known and probably hitherto the least used system of weaving is what is known as "warp-weaving" or knitting. This system is the weaving or knitting together or interlacing of a number of "warp-threads" only, woven or knitted together along the length of the fabric, as shown in Fig. 53, without the use of any weft running transversely.

Ordinary woven fabrics are woven of a certain width in parallel lengths, and the fabric has afterwards to be cut and shaped into articles of clothing or whatever shaped articles may be required. Hitherto the only method known of making fabrics which are shaped in weaving them, for articles of clothing and the like, has been by knitting; and the fabrics are then shaped (or "fashioned" as it is called in the trade) by methods fully explained in a paper read by the writer at the meeting of this Institution at Nottingham in 1870, and published in the Proceedings for that year (page 127).

In the present paper it will be shown that such *shaped* goods can now be made by warp-weaving or knitting; and a machine which effects this is the special subject of this paper.

In this machine the threads are woven or interlaced by the immediate touch or action of three parts, which for convenience are called the three primary parts. These are—the troughs A, shown in Figs. 3 to 7, Plate 88; the needles B, shown in Figs. 1 and 2; and the hooks C, shown in Figs. 8 and 9. It will be more easy to understand the machine, if the manner in which these three primary parts act upon the threads, so as to weave the fabric, is first described; their respective positions in the machine are shown in the full-size transverse section, Fig. 15, Plate 89.

There is one of each of these three primary parts to each thread in the width of the fabric to be woven, and at least one additional needle. Thus if the loom is weaving 1000 threads, then for weaving the simplest and most usual fabric there will be 1000 troughs, 1001 needles, and 1000 hooks.

All the warp-threads to be woven are ordinarily wound upon a weaver's beam, in the usual manner of preparing a warp for an ordinary loom, and the beam is hung upon an axle in bearings above the warp-weaving machine; or in some cases, as will be described later on, the threads are taken direct from the cops, spools, cones, or bobbins, on which the yarn is delivered by the spinner. Each thread of the warp is led downwards from the beam, and is passed into and through a trough. In Figs. 16 to 20, Plate 90, these primary parts are shown in five different positions in their cycle of movements, drawn double full size.

Each trough A when at rest is equidistant between the stems of the needles B on each side of it, and so that the lowest part of the lips of the lower orifices of the row of troughs is just (and only just) above the tops of the stems of the row of needles. Thus it will be seen that, when the row of troughs is moved sideways (say to the left), over and across the row of needles, Fig. 16, Plate 90, exactly as far as the distance between the centres of two contiguous needles, each thread will be laid across and over the stem of one needle.

The needles then move backwards or retire, Fig. 17, so far that the point of the beard of each needle passes over the thread which has been laid across its stem.

The beard of each needle is then pressed into the eye or groove of the needle, Fig. 18, Plate 90, by a presser, which will afterwards be described; while the point of the beard of each needle passes into and safely through the loop of the fabric, Fig. 19, which is on the stems of the needles in front of the hooks C. Then the needle retires further, so that its head passes a certain distance behind the face or front of the row of hooks. Thus a certain length of thread is pulled by each needle against the face of each hook, and through each trough from the beam of warp, and through the loop of the fabric which was on the stem of the needle, and which is drawn over the head of the needle by the hook. While the heads of the needles are behind the troughs, the troughs are again moved sideways (this time to the right) into their former position.

The row of hooks is then made to descend, so that the underside of the bend at the top of each hook just presses on each thread; and then the needles are made to advance and the hooks to descend simultaneously, Fig. 20, Plate 90, so that the loops already pulled by the needles are held down by the hooks, while the row of needles continues to advance to their former position. This completes the cycle of motions of the three primary parts, which is effected by each revolution of the main shaft of the machine.

Now if, during the next revolution of the main shaft, the row of troughs were made to move sideways again over the needles (this time to the left) and then back to their first position as before described, then each needle in the machine would make each thread into a chain, by drawing one loop of each thread through the previously made loop of the same thread; and thus a machine with 1000 needles would make a set of 1000 chains, one chain being made of each thread in the machine; but as each chain would be quite independent of the contiguous chain on each side of it, the machine would not make a cloth or woven fabric.

But if, after the row of troughs has been made to move sideways one needle to the left, so as to lay the threads over the needles as

before described, the troughs are made to move again in the same direction to the extent of one needle more before the needles again come forward to receive a fresh row of loops, then each thread will be passed under the needle next to the left of that on which the last loop was formed. Then if the row of troughs be made to move one needle back to the right, each thread will form a loop on the needle next to the left of that on which the first loop was formed. Then if, before the needles again come forward to receive a fresh row of loops, the row of troughs be again moved to the right, each thread will be passed over the needle upon which the first loop was made, ready to form a loop upon it again. Thus each thread forms a loop, first on one needle, then on the one next to it, then back again on the first, and so on. Thus a cloth or woven fabric is formed.

In goods made with stripes of different-coloured threads, the alternations of a certain number of movements of the troughs to the right, and then a certain number to the left, may be made to produce a number of stripes, either straight or in various kinds of zigzags.

To vary the closeness of the weaving, it is only necessary that the distances to which the row of needles and the row of hooks retire should be varied ; thus shorter or longer loops will be pulled by the needles and held by the hooks, and so a more or less closely woven fabric will be produced. In an ordinary loom with a warp and a weft, if the closeness of the weaving, or the closeness with which the threads of the weft are laid, were to be altered, the fabric would be woven more or less open, but its width would not be appreciably altered. But warp-woven fabrics have a different property or nature : so that, if the machine is weaving a fabric of a certain yarn on a certain number of needles with a certain closeness of weaving (that is, with a certain length of loops), and if the machine be then altered so as to draw slightly longer loops and so weave slightly more open, then the width of the fabric is at once materially increased. It is by using this property of the warp-woven fabrics that this machine has been rendered able when desired to *shape* the fabrics while they are being woven, that is, to increase or diminish their width during the operation of weaving.

How the various necessary movements are communicated from the main shaft of the machine to the three primary parts, will now be described in connection with the drawings, Plates 88 to 99.

Troughs.—Each trough A is attached to the trough-bar A1, Fig. 15, Plate 89, by being driven into a suitable groove in the bar; and the walls of the grooves are then partly bent over and partly riveted over, so as to secure the troughs on the bar. The trough-bar is bolted to the trough-slide-bar A2, which hangs on the vee-shaped part of the main bar E, and slides to and fro upon it. The trough-bar is adjusted in height by the screws A3, so that the lower lips or orifices of the troughs will just pass over the stems of the needles, as close to them as possible, so as not to touch them, but to allow only just sufficient room for the threads to pass between the troughs and the needles. On the back of the trough-slide-bar A2, Figs. 24 and 25, Plate 93, there is a toothed rack, into which gears a small toothed sector A4 attached to the bottom of a vertical spindle; to the top of the spindle is attached a larger sector, at the left side of which are ratchet-teeth A5, while at the right side are ratchet-teeth A6, acting contrariwise to the teeth at the left side. The pitches of the teeth on the two sectors and on the rack are so arranged that, when the ratchet-sector is turned one tooth to the right, the trough-bar is moved one needle to the left, and *vice versâ*.

Two chisel-shaped ratchets A7 and A8 are attached to the triangular ratchet-frame A9, Plate 93, so that, according to the position sideways of the ratchet-frame, either but not both of the ratchets will act upon the ratchet-teeth when the triangular frame is moved forwards by the cam A10 on the main shaft F; and will move the trough-bar either one needle to the right or one needle to the left, in accordance with the position sideways in which the ratchets are held by the frame. There is a wedge-shaped spring-latch A11 acting upon a projecting wedge-shaped stud on the underside of the ratchet-frame, which allows the frame to be moved either to the right or to the left, so as to put into action either the left or the right ratchet; and then to keep in action whichever is put into

action, until the frame is again moved sideways in the opposite direction. To the upper surface of the ratchet-sector there is attached at the left side an inclined finger A12, and another similar finger A13 is attached at the right side. These fingers can be adjusted at such a distance from each other that, when the right ratchet has turned the ratchet-sector say two teeth to the right, then, while the ratchet-frame is retiring in its backward stroke, the left projecting stud A14 on the top of the ratchet-frame will come in contact with the left finger A12, and will push the ratchet-frame over to the right, whereby the right ratchet will be put out of action and the left ratchet will come into action. Similarly, when the ratchet-sector has been turned two teeth to the left, the right finger A13 will act upon the corresponding right projecting stud A15, and will push the frame over to the left; and so on. Thus the trough-bar and troughs will be shifted two needles to the left for one revolution of the main shaft, and then two needles to the right for the next revolution; and so on.

At the end of each traverse of the trough-bar it is absolutely necessary that each trough should stop and remain at the exact centre of one of the spaces between the needles; and this is effected in the following manner. On the front face of the right-hand end of the trough-slide-bar A2, Figs. 28 and 29, Plate 94, there is formed a row of wedge-shaped teeth A16, of the same pitch as the needles of the machine; and facing these is formed a corresponding set of wedge-shaped teeth on a bar A17, which is hinged by a spring to a projection E1 on the main bar E. When the trough-slide-bar is completing its traverse, the set of teeth on the hinged bar A17 is pressed towards and against the set of teeth A16 on the trough-slide-bar; and the two sets of teeth are so arranged that, when they are engaged and pressed together, the trough-slide-bar must take and keep its exact longitudinal position. The hinged bar is pressed forwards against the trough-slide-bar by the lever A18, Figs. 26 and 27, which is actuated at the right times by the cam A19 on the main shaft F.

There is a further apparatus attached to the machine for enabling the varying zigzag stripes before mentioned to be made by

controlling the movements of the ratchet-frame and the trough-bar to the left and to the right in varying orders according to a certain plan fixed beforehand.

Needles.—The needles B are held at their back ends by hinged plates B2, which press them into grooves and holes in the needle-bar B1, Fig. 15, Plate 89. This bar is held at the back by two joints B3, which are attached by joint-pins to the two arms B4 of the rocking-shaft B5, Plates 91, 92, and 95; the ends of the shaft rock in bearings in the end frames or legs H of the machine. The upper ends of the two rocking arms B4 carry two bowls B6, each of which is pushed forwards by a cam B7 on the main shaft F; and the bowls are pulled backwards by the springs B8, which pull the needle-bar B1 backwards. The extent of the backward movement of the bowls, and of the consequent backward movement of the needle-bar and needles, is controlled by two double needle-controlling hooked stops B9, which take hold of and stop the four projections B10, two on each rocking arm B4. The positions of the stops B9 are controlled by the two wedges B11, which are attached to the bar B12 that slides longitudinally in bearings attached to the machine. Thus it will be seen that, by sliding the bar B12 and its wedges to and fro longitudinally, the distance of the backward movement of the needles is easily controlled.

The front ends of the needles rest and slide upon the grooved top of the knocking-over bar D, Fig. 15, Plate 89, which is held at each end by the legs or end frames H of the machine.

Presser.—When the needles have moved backwards so far that the points of their beards are safely over the threads laid across their stems, Fig. 17, Plate 90, then the presser B13 is caused to descend, but only so far that its rounded lower edge presses upon the beards, Fig. 18, and holds their points down in the eyes or grooves of the needles, until the points of the beards are safely entered into and have passed through the loops last made of the fabric. The presser then rises, so as not to touch the needles or

their beards, Figs. 19 and 20; and it remains in this raised position until the needles have come forward, Fig. 16, and the troughs are again about to traverse across the needle-stems. Now it is evident that, if a needle should be slightly strained and raised, so that it does not rest upon the bottom of its groove in the knocking-over bar D, the trough which has to traverse over this needle might push the needle-stem to one side and break the needle, and possibly also the trough. In order to prevent this, before the troughs traverse over the needle-stems the presser B13 is made to descend further than before, so as to press all the needle-stems down against the bottoms of the grooves in the knocking-over bar D, Fig. 16, so that then all the troughs can safely traverse over all the needles. When they have done so, the presser rises again, Fig. 17, so as to be clear above the needle-beards until they have again retired to the right position for being pressed.

The presser B13 has six arms B14, Figs. 11 and 12, Plate 88, which project backwards and under the main bar E, Fig. 22, Plate 91, and are hinged by pivots to brackets B15, attached to the back of the main bar E. Springs B16, attached at the lower end to the arms B14 and at the top end to a longitudinal bar T, Fig. 21, tend always to lift the presser upwards.

On the top of the presser B13 are formed wedge-shaped surfaces B17, Figs. 32 to 36, Plate 96; and acting upon these are other wedge-shaped surfaces formed on the underside of a longitudinal bar B18, the upper face of which bears and slides against the under surface of the main bar E. If this bar is traversed endways to the left in the direction of the arrow in Fig. 35, the combined action of the two sets of wedges will cause the presser B13 to descend; whereas if the bar is traversed to the right in the direction of the arrow in Fig. 33, the wedges will be withdrawn and the presser will be lifted by the springs B16. The traversing of the bar to and fro endways is effected by the cam B19 acting upon the two bowls which are shown at the end of the bar in Fig. 23, Plate 92, and in Figs. 40 to 42, Plate 97.

It will be seen that the wedges which actuate the presser B13 have a strong tendency to bend or curve the main bar E upwards

between its two ends where it is secured to the main framing H of the machine. The presser also has a strong tendency to bend or curve downwards in a similar manner the knocking-over bar D; for, although the power required to press the beard of one needle into its groove is small, the power required to press the beards of the whole 1008 needles into their grooves is very large. If the combined curvature of these two bars were to amount in the middle of the width of the machine to as much as one-fiftieth of an inch (that is, one-hundredth of an inch for each bar), this would be sufficient to make the difference between pressing the beards thoroughly and properly, and entirely failing to press them. It is necessary therefore, in order to enable a machine of this class to make cloth in one width (of 7 feet as in this machine), that the bar E and the bar D should be held together firmly and strongly, without in any way interfering with the continuity of the row of needles. This is effected by the connectors N, Fig. 15, Plate 89, which are made of steel plate of the shape shown, each being thin enough to pass easily between any two needles in the row. The upper ends of these connectors N hook into a groove in the main bar E, and are held there by the piece of brass E2 and by solder. The hook at the lower end of the connector N hooks into a groove in the knocking-over bar D. It will thus be seen that, in order to hold together with great firmness and rigidity the main bar E and the knocking-over bar D, and to prevent these two bars from being sprung apart, and thus to insure the accurate and perfect pressing of all the row of needles, it is only necessary to insert a sufficient number of these connectors between the needles, at convenient distances apart along the whole width of the machine.

Hooks.—The row of hooks C is held by the hook-plates C1 in the hook-bar C2, Fig. 15, Plate 89, in the same way as the needles are held in their bar. The hook-bar C2 has attached to its lower edge two arms C3, Fig. 21, Plate 91, which are jointed by pins to the two arms C4 of the rocking-shaft C5; at the other end of each of these rocking arms is a bowl C6, which is moved backwards by a cam C7 on the main shaft F. The springs C8, which are attached at

their upper ends to the hook-bar C2 and at their lower ends to a fixed bar, pull the hook-bar and row of hooks downwards, and so keep the bowls C6 always pulled forwards and pressed against the cams. The extent of the downward movement of the row of hooks is controlled by the two double hook-controlling stops C9, which take hold of and stop the four projections C10, two attached to each of the arms C4. The positions of the stops C9 are controlled by the action of two wedges C11, attached to the bar C12, which slides longitudinally in bearings attached to the machine, in a similar manner to that already described in connection with the movements of the needles. By sliding the bar C12 with its wedges to and fro longitudinally, the distance of the downward movement of the hooks is easily controlled. The upper ends of the hooks slide in the grooves in the front of the knocking-over bar D, Fig. 15, Plate 89.

Reservoir Rod.—It will be seen that, when the needles are pulling their loops from the threads through the troughs and against the front of the hooks, Fig. 19, Plate 90, there must be a rather sudden snatch upon the thread, which will then rest until the needles have advanced and again retired to this same spot, and are again pulling another row of loops; this will produce again a sudden snatch upon the thread, and thereby cause a sudden small rotation of the beam on which the threads are wound. In order to prevent this motion from being continued too far by the momentum of the beam, a certain amount of tension, drag, or friction is requisite upon the beam; and in consequence of these sudden jerks of the threads, the beam has to be suddenly started into rapid motion, then stopped suddenly, and then started again. In delicate yarns this is liable to break the threads, and thus cause the speed of machine to be limited to a slow rate. To obviate this difficulty there is interposed near to the thread-troughs an arrangement called a reservoir rod, which will be understood from Fig. 21, Plate 91. The longitudinal rod A20 is mounted in the machine so that it can rock upon its centre; and arms attached to it carry another smaller

rod A21, which rocks with the larger rod A20. After leaving the beam A22 the thread is passed down and under the rod A20, then up and over the rod A21, and thence down to the trough A. At one end of the rod A20 is an arm pulled backwards by a spring A23, which keeps the smaller rod A21 pressed upwards against the threads; but when the snatch or sudden pull comes on the threads, the reservoir rod A21 gives way, and allows the threads to be drawn from it without producing any great snatch upon them; and then, while the needles are performing the rest of their motions and are not pulling more thread, the reservoir rod A21 is being raised again into its former position by the pull of the spring A23, and is thus drawing thread off the beam ready for the next row of loops. By this means the beam is kept steadily in motion at almost a constant rate, which enables the machine to be driven at a much higher speed than could otherwise be attained.

Re-threading.—In the ordinary warp-knitting or weaving machines at present existing the ordinary warp-guide is used, as shown in Figs. 49 and 50, Plate 99. In the ordinary warp-machine, when all the yarn on a beam is worked up and the machine requires a fresh beam, the ends are cut, the old empty beam is taken down, and a fresh full beam is put up. If there are (as in this machine) 1008 threads, either the end of each thread in the machine has to be tied to each thread of the new full beam, or each of the 1008 threads has to be threaded through its warp-guide; this necessitates either the tying of 1008 knots, or the threading of 1008 ends, which in an old-fashioned warp-machine takes ordinarily about three hours; but as the speed of the old warp-machines is very slow, the operation requires to be performed only about once in two or three or more days. As the speed of the new machine however is so much greater, namely 120 courses per minute instead of only about from 30 to 50 courses per minute, a beam is often emptied in from one to two days; and it is evidently very important that as little time as possible should be lost in putting in a fresh beam and re-starting the machine. By the following arrangements this can now be done in about twenty to thirty minutes.

It will be seen that the troughs A are open in front, Figs. 3 to 7, Plate 88, so that a thread can be passed into each trough without threading its end through the trough; and the open mouths of the troughs are at a distinct and definite distance apart from one another. When in the warping machine the beam A22 is full, Fig. 37, Plate 97, the threads from the creels, after having passed through the reed J1 towards the beam, pass over and rest on another vee-shaped reed J2, the pitch of the vees corresponding exactly with that of the troughs. Between the two reeds there is placed under the threads a grooved trapping-bar J; all the threads in the warping machine (in this case 504, being half the width of the warp-weaver) are lying over the trapping-bar, and all at exactly the same distance apart from one another as are the mouths of the troughs. The wedge-bar J3 being now placed over the threads and over the groove in the upper part of the trapping-bar J, Fig. 37, is pressed downwards into the groove, as shown in Fig. 39; and thus takes hold of or traps every one of the 504 threads, at exactly the same distance apart as the mouths of the troughs. All the threads of the warp are then cut off on the creel side of the trapping-bar, Fig. 37; and the trapping-bar with all the threads attached to it is now fastened to the cheeks or ends of the beam, as shown dotted in Fig. 37. When the beam is put up in the weaving machine, the trapping-bar is again loosed from the beam, and is brought down towards the mouths of the troughs, and placed into position with regard to the troughs, as shown dotted in Fig. 22, Plate 91. Thus if the trapping-bar is placed so that each thread is opposite to the mouth of a trough, and if the trapping-bar is then pressed against the mouths of the troughs and made to descend and slide down to below the troughs, as shown full in Fig. 22, all the 504 threads will thereby have been threaded into their troughs. The same operation is then repeated for the other half of the machine; and thus the 1008 threads are threaded, and the machine is ready to be started again, in from twenty to thirty minutes. This is done by the girl who attends to the machine, with a younger girl to assist her during the time of threading-up, instead of requiring three persons for three to four hours.

Fringing.—For some goods, such as towels, bath-sheets, antimacassars, and others, it is very advantageous to be able to make in the machine a fringe at both ends of each article woven, such as a towel. The arrangement for doing this is shown in Fig. 21, Plate 91. On the front of the machine below the hook-bar is a longitudinal fringing-bar L, in which are held a row of hooks. When the machine is at work weaving, these hooks lie out of the way behind the fabric woven; but when a fringe is required to be made, the machine is stopped, and the fringing-bar with its hooks is lifted up, so that the hooks pass upwards behind the fabric; and if the fabric is pressed against the hooks and the hooks are slightly lowered, they then lay hold of the fabric and pull it downwards, and so draw a long length of thread through every trough and round every needle; the length of the loops thus drawn is arranged to be double the length of the fringe required. The fringing-bar with its hooks is then slightly lifted again, and the fabric is unhooked from them; and the fringing-bar is made to descend to its former position. The machine is then started weaving again in the ordinary manner; and this locks and interweaves together all the long loops drawn by the fringing-bar. After the fabric is all woven, the long loops are cut across the middle of their length, thus producing a thoroughly satisfactory fringe at each end of each towel. It would unduly lengthen this paper were a detailed description to be given of all the arrangements by which these motions of the fringing-bar are effected.

Selvedge.—In an ordinary loom (with a warp and a weft) say 84 inches wide, if it were desired to alter the loom to weave say four widths of fabric with two selvedges to each width, there would be much expense in altering the loom, and a great loss of space in three parts of the loom to allow for the three shuttles to lie in the three spaces between the four widths of fabric. But in this machine a selvedge can be produced in a few minutes in any part of the 84 inches width of the machine, without any expense, and with the sacrifice of only the space occupied by one needle, that is, in this machine one-twelfth of an inch.

In warp-fabrics of the class now dealt with, each selvedge-thread has the full length of loop pulled from it by the needle during only every alternate row of loops; and thus less thread is used in forming the selvedge than is required for the other threads of the fabric. Therefore to produce a selvedge on any part of the width of the machine it is only necessary to take three threads from the beam, and to lead them to the back of the machine, as is shown in Fig. 21, Plate 91, where each set of three threads at each pair of selvedges of the fabric is led to and wound upon a bobbin marked M. This bobbin is held by its axle in a forked guide, so that it rests upon the narrow wheel or drum M1, the shaft of which is held in bearings at each end in the framing of the machine, and is driven from the main shaft at a suitable speed. As each set of three threads is led to the bobbin M, it is passed through a guide M2, which has a longitudinal traverse given to it so as to lay the thread equally upon the barrel of the bobbin. To produce a pair of selvedges, a pair of bobbins M3 full of thread are mounted upon a horizontal rod in the front of the machine, and upon each of these bobbins hangs a kind of flat-hook or bonnet M4, which produces a regular and equal drag upon the thread as it is unwound from the bobbin. These two threads are led to the two outer troughs in each set of three troughs whose threads have been led from the beam to the back of the machine; and the two threads are threaded through these two outer troughs, and led to the needles which are to be the selvedge needles. If the machine is then made to weave in the ordinary manner, a selvedge will thus be produced at any required part of the machine, with the loss of only one-twelfth of an inch to each pair of selvedges.

Shaping.—The movements will now be followed whereby this machine produces shaped or fashioned fabrics, such as the bodies of vests for ladies: such bodies being shaped properly, so as to fit the figure. This shaping is produced, as before mentioned, by moving the wedge-bars B12 and C12, Fig. 31, Plate 95, and thus varying the lengths of the needle and hook pulls, and the consequent width of the fabric. These two wedge-bars are connected to the

opposite arms of a lever P, which works upon the fixed centre P1. The wedges are so set that, by moving the lever P, whereby both the wedge-bars are moved longitudinally, the needle-controlling stops B9 and the hook-controlling stops C9 are simultaneously moved; and thus the lengths of the loops pulled by the needles and held by the hooks can be varied simultaneously by moving the lever P while the machine is running at full speed.

The main features of the mechanism which automatically controls the movements of the lever P and the wedge-bars are as follows. A chain on a suitable guide is caused to travel in the direction of its length through one link for each revolution of the main shaft of the machine; and for this purpose the chain invented by the French engineer Vaucanson, and well known as "chaîne Vaucanson," has many properties which render it peculiarly suitable. Upon the chain are arranged two rows of inclines or wedge-shaped projections, at any desired intervals apart; each row of inclines sets in motion an arrangement of levers and ratchets with a worm, gearing into a rack on the wedge-bar B12. One row of inclines causes the wedge-bar to move in one direction, and the other row causes it to move in the opposite direction. Thus, as the chain advances, an incline of one or other row comes into action, whereby the wedge-bars are moved in one or other direction, and consequently the length of the loops pulled is increased or decreased as required; and thus the width and shape of the fabric are governed by the number and position of the inclines upon the chain.

The description of the many small and complicated details of this automatic mechanism for shaping the fabrics is not here attempted. Shaped fabrics are made automatically by this mechanism at the rate of 120 courses per minute, either upon the whole width of the machine, or with the whole width divided up into any desired number of divisions. Thus from three to five bodies for shaped ladies' vests, or from six to ten sleeves, can be made simultaneously, all fully shaped, at the rate of 120 courses per minute, without stopping, except for about three to four minutes to make a fringe or finish at the commencement of each set.

Weaving from Creel.—In some cases the machine is arranged for drawing its threads direct from the cops or cones as received from the spinners, without the threads being re-wound or warped or beamed. In such cases the cops or cones of thread are placed upon a special stand or creel, Plate 98; Fig. 43 is an end view of the creel, Fig. 44 is a front view of part of it, and Fig. 45 is a part plan with the top removed. The cones of thread R (of which only four are shown in each view to avoid confusion) are placed upon pegs, which are set in rows one above another. Rows of top guides R1 are arranged so that one guide is over each cone of thread, and a corresponding number of guides R2 are also placed along the front of the creel; each thread is passed from its cone through the top guide immediately above it, then through a front guide, and is thence led to the weaving machine. Two of these creels are placed behind the machine, according to the arrangement shown in the plan, Fig. 46, where the directions of the first and last threads only, from each creel, are indicated.

In Plate 99, Figs. 47 and 48 show how the threads are guided at the weaving machine, and how the necessary tension is produced; Fig. 47 is a part front view and Fig. 48 a part section of the arrangement. Four fixed rods R4, reaching from end to end of the machine, are carried by brackets. Three movable rods R3 are fixed to side-frames, which hook on to, and are free to turn upon, the top fixed rod R4 in such a manner that the movable rods can either be placed between the fixed rods as shown, or can be turned up into a position such as indicated in dotted lines in Fig. 48, clear of the fixed rods. The threads coming from the creel are passed through the reed R5, and over the fixed rods, down to the thread-troughs A. The movable rods are then lowered into the position shown, between the fixed rods, and are held there by a screw R6. Thus the threads pass alternately over a fixed rod and under a movable rod; and by adjusting the screw R6 the position of the movable rods between the fixed rods is regulated, and the tension on the threads can thereby be increased or decreased to the required amount.

Construction of Presser.—The last point of peculiar construction which will be noticed is the method of making the grooved part of the presser, Figs. 10 to 14, Plate 88, where the walls of the grooves of the presser press upon the beards of the needles. The presser must have recesses or grooves formed in it, so that the hooks when they rise above the fabric can pass up into these grooves; and thus there is only a small wall of metal at the side of each hook and over each needle, which wall has to stand all the work and wear of pressing the needle-beards and also of guiding the tops of the hooks. These walls should therefore be of hard and tough metal—in fact should be of tempered steel; and if they were formed by cutting or grooving them out of solid steel, the expense would be very great. To avoid this, each wall is made separate, and punched out of steel plate of the shape shown in Figs. 13 and 14. Longitudinal recesses are planed in the bar B13, as shown in Figs. 11 and 15, for the walls to fit into; and they are placed in these recesses and there held at the right pitch or distance apart by a comb-bar or chuck, and while so held are soldered to the presser-bar, as shown in Figs. 10 to 12. Besides attaching each wall firmly to the bar, the solder fills up the spaces between the walls, except where the hooks have to pass between them, as shown. A sample of such a presser is exhibited.

There are many other points of peculiar construction and detail about this machine which might be interesting, but the description of which would take too much time. The machine itself is now at work in the Exhibition.

Discussion.

Mr. PAGET exhibited an enlarged working model of the machine, thirty-two times full size, by means of which the action of the three primary parts was illustrated in weaving a piece of bell-rope into a portion of a fabric. He also showed specimens of the actual primary parts themselves, fixed upon a card in the relative positions that they occupied in the machine, of which a section was also drawn upon the card, as shown in Fig. 15, Plate 89. An extensive collection of samples was also exhibited of the various kinds of work produced by the machine. One of these was a towel, at the ends of which was seen the fringe produced by the apparatus described in page 481; and attention was drawn to the closeness of the weaving. The great difficulty with warp weaving hitherto had been to weave a close solid fabric, because the loops could not be got over the heads (or hooks) of the needles in close weaving, as they then fitted the needles too tightly. The reason why with this machine the tight loops could be got over the needles was the addition of the hooks, for pulling the loops over the heads of the needles and for holding the loops after they had been pulled over the needle heads, whereby the loops were tight after having passed over the needle heads.

A sample exhibited of striped weaving was produced by making the troughs shog twice to the left, then twice to the right, and so on. But if instead of two they made four or more shogs each way, then instead of a stripe a zigzag was produced, as illustrated by another sample. The machine had been further elaborated so that the number of shogs right and left could be varied automatically without stopping the machine, as illustrated by another sample, in which during one portion of the weaving the troughs were traversing two needles to the right and two to the left; during the next portion four to the right and four to the left; during a further portion six to the right and six to the left; and then again they resumed traversing two to the right and two to the left. These and other peculiar permutations of pattern were produced by the apparatus which was governed by the Vaucanson chain, as explained in page 483; the

number and position of the inclines upon the chain were adjusted beforehand according to the pattern desired.

As an example of shaping the fabrics, a sample was exhibited of a lady's petticoat which had been woven and shaped on the machine. By making the loops longer towards the bottom of the fabric it was widened at that part; and then step by step, at a varying number of stitches apart, the length of the loops was reduced, thus reducing the width. A still further development of the shaping was shown in a sample of a lady's vest woven to suit the figure. It was shaped on the machine at the rate of 120 courses a minute; and this was the only machine that had been able to weave in warp fabrics an article of any kind shaped automatically.

The President enquired whether the lady's vest shown was woven in halves.

Mr. Paget replied that the body was woven from the front upwards, over the shoulder, and down again at the back. The weaving began at the bottom in front, then widened out to suit the hips, then narrowed in to suit the waist; then it widened again to suit the bust, and then narrowed again to suit the neck; and then the weaving went over the shoulder and down the back. It was narrowed from the shoulder to fit the waist, again widened to fit the hips, and ended behind, level with where it had started in front. The lines of the two pairs of selvedges were seamed by hand afterwards from each arm-hole downwards; the selvedges were so good that it was doubtful whether the seam could be seen at a little distance, even though it was known to be there. The whole of this work was woven from beginning to end at 120 courses per minute without varying. The sleeves were also woven on the warp machine, and were afterwards sewn in at the arm-holes of the vest by another machine. In this particular specimen it so happened that the sleeves had been made on a knitting machine, and not on the warp machine; and in this case therefore the web of the body was opened out at the shoulder, and was actually put upon the needles of the knitting machine, and the sleeves were then woven on to the body. The

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sleeves woven and shaped on the knitting machine were made at the rate of only about 25 courses a minute, and only two sleeves were knitted at once, instead of six sleeves being woven at once on the warp-weaver and at the rate of 120 courses a minute; and instead of teaching an operative to work the weaving machine in about a fortnight, it required months for a girl to learn to work the knitting machine.

Another curious development of warp weaving was that the same machine which wove an exceedingly coarse cloth like a horse-rug, and a very fine thin soft texture for making woollen vests such as would be liked in a hot country by those who would avoid rheumatism, also wove the light and open sample now shown of a lady's cloud, which was 8 feet wide when stretched out. The clouds were woven $6\frac{1}{2}$ feet long, and five at once in the width of the machine, the set of five being completed in a trifle over $2\frac{1}{2}$ minutes: so that it might be said each cloud required only about half a minute to be woven on the machine. History told of a certain French king who had a pair of stockings woven for his wife, so fine that they would pass through a finger ring. The cloud now exhibited was considerably wider than any pair of stockings, as it was 8 feet wide, and when doubled lengthways was therefore equivalent to 16 feet width; and when thus doubled it easily passed through his finger ring, as he now showed.

Mr. Benjamin A. Dobson, Member of Council, had had the pleasure of examining this warp-weaving machine in great detail, and had been much surprised to find how easy it was to forget many of the points connected with it; but on listening to the paper just read they had been brought back again to his mind. So far as he understood the machine, it did its work most perfectly; and in regard to speed it exceeded anything yet attempted in that process of manufacture. If there had been any defect in it, and if he had been able to find it out, he should certainly have drawn attention to it; but after following the description given in the paper, and seeing the clever manner in which the parts had been combined to produce certain mechanical results, and the smooth way in which those

results were produced upon the machine in work, he thought it would be admitted that a great amount of scientific and mechanical ability had been brought to bear for making the machine as perfect as it was. He had been astonished at the speed at which the machine would work, combined with its smoothness. Having been accustomed to machinery of a similar description, he should have thought that there would be such an amount of vibration and concussion as would prevent some of the sensitive and delicate parts from performing their duties thoroughly without a large amount of wear and tear; and he was much pleased to be able to compliment the author on the way in which that difficulty had been overcome. He had never seen a machine of that width with less spring in all its parts; in fact the way in which all those difficulties had been foreseen and met in the construction of the machine he considered to be a valuable lesson in mechanical engineering.

The variation in the nature of the work produced was also astonishing. No doubt some might be inclined to question the speed at which the articles were produced; but he was in a position to confirm all that the author had stated with regard to that point. The celerity with which the machine could be changed from one material to another was also very remarkable; he had seen no machine of a similar description that admitted of the same amount of change, or that admitted of being changed in so short a time. The method of changing from one quality of warp to another he also considered a most valuable invention for practical use in the manufacture of woven fabrics. Although that might not strictly speaking be regarded as mechanical engineering, yet it showed the necessity for a mechanical engineer to be able to apply his common-sense and his education as an engineer for producing satisfactory results which would enable him to work his machine to the best advantage.

Having also examined in detail the old knitting machines, which were at the present day employed in large numbers in France, he had found they were beautifully manufactured. The movements were admirably combined, and in regard to work the machines might almost be called perfect in their construction. But they involved

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the defective principle that there was only one thread to knit with, and this had to traverse the whole width of the machine, which it could do only at a speed that was limited by the operation of making the loops somewhat as described by the author, although it was done rather differently in those machines. Consequently, whatever might be done to improve those machines, they never could by any possibility rival the speed of this warp-weaving machine, because, as had been seen, there was here a separate thread for every needle or loop, and the only movement required in the machine in the direction of its width was simply the movement of the row of troughs to the right and left to a very small extent. The high speed of weaving was arrived at by adopting this entirely different principle of a very small lateral movement, which allowed of increasing the speed to practically from six to ten times faster than in the ordinary knitting machines, according to the material employed and the nature of the work done. Although the motions that had been described seemed unusually complicated, he thought every one who examined the machine would admit that its complication was more apparent than real. If the motions on each side of the machine were taken off, it would be found that the interior portion of the mechanism, which absolutely produced the fabric, was simply a repetition of a few elementary parts; and if the mode of forming the loop were once clearly comprehended, there would be no difficulty he thought in following all the other movements required in the machine.

The shaping mechanism, which had not been described in detail in the paper, was certainly one of the most beautiful applications of a simple automatic motion that he had ever seen, and it was worth careful study to understand how that motion acted. There were at least six motions in that portion of the machine; and to explain all of them fully would require a paper of almost the same length as that now read, which therefore had necessarily been limited to a general description of the machine. Altogether he considered this was one of the most remarkable machines of modern days; and it showed what ingenuity and perseverance could do in the way of perfecting a machine by the application of mechanical principles.

Mr. JULIUS BOEDDINGHAUS asked whether the same machine would do for thick and thin fabrics, as for example coarse wool and fine silk.

Mr. PAGET replied that the machine would weave either coarse sacking for nail-bags or much finer articles than any of the samples now exhibited. An enthusiastic friend, who was well versed in all the details of hosiery manufacture, had expressed the opinion that before long the machine would be able to weave handkerchiefs of the finest silk. Although he did not himself at present go quite so far as that, yet he would not say that it never would be done. The range already covered however was a pretty extensive one.

Professor ALEXANDER B. W. KENNEDY, Member of Council, had had the pleasure six months ago of spending a couple of days in the examination of this machine, and had therefore had a good opportunity of seeing what a beautiful machine it was; and he regarded with the utmost admiration an invention displaying so high a degree of mechanical engineering ingenuity. In common with Mr. Dobson he had had the opportunity of timing a great deal of the work, and seeing exactly how the machine produced fabrics of different kinds. The machine which he had then seen at work was not the particular one now shown in the Exhibition, but an earlier one, though in principle it was exactly the same. It had 1,008 needles, pitched twelve to the inch; and all the work that he saw produced was done with the same machine and with the same pitch of needles.

The first work that he saw done was a somewhat heavy towelling, of which the author had now shown an example. The machine being 84 inches wide, the towels were made in three parallel sets, each set being 28 inches wide. The machine being started, it made the right number of courses, and then stopped automatically. When it stopped, the attendant put in gear the hook frame for making the fringe, pulled out the requisite length of fringe, withdrew the hook frame, and started the machine again; then it again went on automatically to the right length, and so on, doing everything on its own account between the stoppages. The whole time of weaving each towel

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length, including the fringe, was $15\frac{1}{4}$ minutes: so that there were twelve towels made entire per hour, and nothing had to be done to them but cutting the fringes in halves.

What had struck him most was what he next saw produced in the machine. It was a cloud, or rather five clouds woven side by side. They were made with $2\frac{1}{4}$ courses of loops per inch of length; that is, the fabric as it was woven moved forwards one inch for every $2\frac{1}{4}$ courses. It was precisely the same fabric as the specimen which had now been shown. Immediately after the clouds had been finished with a certain very fine yarn, then without any change whatever, excepting the motion of one lever if he remembered rightly, the pitch or closeness of the work was altered from $2\frac{1}{4}$ courses to 67 courses per inch of length; and at once the machine went on working the close-woven and shaped garments which had just been exhibited. The stitch was the same, excepting only that in one instance it was 4-9ths of an inch long, and in the other it was only 1-67th of an inch. Until seeing this done, no one would imagine that the open cloud and the close-woven material were absolutely one and the same fabric, woven on one and the same machine, without any difference except in the number of stitches per inch. He had got a piece of the fabric that had been cut out where the change was made, in which the piece of cloud appeared like an open netted fringe on the end of the piece of closely woven vest. According to a note which he had made at the time, the length of $6\frac{1}{2}$ feet was finished in three minutes, five clouds being made side by side: which meant that 100 clouds per hour were made on the machine. They were woven continuously, and had afterwards to be cut to the length required. The whole process had to be seen to be believed, as had also the shaping of the shaped vests; and the simplicity of the manner in which the latter operation was carried out had certainly not been exaggerated by the author.

When the machine was working at that extraordinarily rapid rate, it would be no good if two or three hours had to be spent in changing the beams; and here the author's ingenuity had developed a plan so remarkably simple that the time now taken in changing the beams was about as many minutes as it used to be hours. The threads wound on the beam were necessarily led off it over a reed

in the beaming or warping machine, the reed being arranged so as to pitch them the right distance apart for the needles and troughs. Instead of taking the threads over one reed only, they were taken across two; and under the threads was placed a grooved wooden trapping-bar, in which they could be held by a wedge pushed in from above. When it was desired to trap or hold them, the threads were lying exactly pitched across the reed, and all that was done was to drive the wedge in, so that all the threads were held fast between the wedge and the two sides of the trapping-bar. All the ends of the threads were thus secured at exactly the proper pitch, corresponding with the reed, which was the same as that corresponding with the needles: so that each thread had not to be threaded separately, but the whole series were simultaneously entered correctly into the open mouths of the troughs. The result he had found to be that the taking out of the two empty beams and putting in two full ones, each containing 504 threads, took only $8\frac{1}{2}$ minutes. The utmost manual exertion was a light pull on the rope of the hoisting gear, which formed part of the machine. The 504 threads of one beam were then entered into their respective 504 troughs, which took exactly ten seconds, and was done by the girl who attended to the machine. The whole of this latter operation, including the adjustment of the few threads which had not entered the troughs quite accurately, took just one minute; and from the time when the trapped ends of the threads were brought to the front of the machine, until the whole 1,008 of them had been properly placed and secured by two courses worked by hand and the traps removed, was not more than $3\frac{1}{2}$ minutes. Threads had then to be taken out at four intervals for spacing the work into five breadths, and new selvedge and mending bobbins had to be put in for suiting the new yarn; but with all this and all other delays, including the overhauling of the needles, the whole time taken by the change of beams, from stopping the machine for the purpose until it started again on the new work, was exactly 25 minutes.

A further point to which he should like to call attention was the regulating or equalising arrangement, or reservoir-rod as it was called in page 478, by which it was contrived that the thread beam

(Professor A. B. W. Kennedy.)
was kept steadily in motion at almost a constant rate, thereby enabling the machine to be driven at a much higher speed than could otherwise be attained. The speed with which the thread was pulled by the needles varied very greatly indeed in each course; but on watching the working of the machine most carefully he had found that the speed with which the thread came off the beam was as far as he could see practically uniform. That was the result of an admirable arrangement, which had also the merit of being very simple; and he only wished that more of such simple contrivances could be found out and brought to so successful an issue.

Mr. Daniel Adamson, Vice-President, had had the satisfaction of seeing the machine working; and being somewhat interested in cotton spinning and the manufacture of soft goods, he would say that practically there was an advantage to the thread manufacturer in the circumstance that for this machine there was only one quality of yarn or thread to make, instead of the usual twist or weft also: because in the latter case, in spinning with 100,000 spindles, where there might be 50,000 spinning warp and 50,000 spinning weft, a great deal of inconvenience might arise if orders were not received corresponding with the relative quantities produced of the two particular kinds spun. It had often occurred that such was the condition of the markets that the spinners had not the chance of regulating their sales so as to meet their powers of production; and in the present case therefore the matter was simplified by dispensing with the weft.

The excellent working model, enlarged to thirty-two times full size, which had been shown in action by the author during the reading of the paper, was a practical illustration that might often be wisely imitated for illustrating the working of a new machine. The needles, of which specimens were exhibited, were in themselves a high-class manufacture, and required both considerable skill to make them and also a highly refined material, for which the author was indebted alike to the engineer, to the metallurgist, and to the steel-worker. The needles were indeed a valuable automatic element in the machine, inasmuch as each had sufficient spring in itself

to bear the depression for passing through the loop, and to relieve itself afterwards, so as alternately to catch hold and let go of the interchanging loops. There were so many parts in the machine that it wanted to be seen many times before its operations could be thoroughly comprehended. By means however of the working model exhibited, containing only four needles, it was much simpler to study their action than in the machine containing 1,008. He remembered what his own experience had been when he left locomotive engineering in 1849 and went to Lancashire, how greatly puzzled he had felt in looking at a mill with 100,000 spindles; but, when he began to look at one spindle only, he found it was not nearly so difficult to comprehend that one as it was to look at 100,000. In the beautiful warp-weaver now described he was greatly interested, and he hoped the author would have a great future for it and be amply compensated for his skill, and that outsiders might soon have the benefit of wearing some of the nice fabrics which were woven so cheaply; it would be a great advantage to the world at large to have such increased comforts at so small a cost. Something too he thought need be said of the skill manifested by the girls who worked these new machines, and thereby acquired an education and a practical experience such as might well be admired by the advocates of technical knowledge and better education for the people generally.

Mr. J. J. Birckel believed this was the only machine for producing fabrics such as were made by spinning, knitting, or weaving, in which there were motions that were required to be controlled automatically within 1–50th of an inch. Such a control had never before been realised in any machine of that class; and its accomplishment might well place the author in the foremost rank of mechanical engineering. Although himself no spinner, he believed the self-acting spinning mule did not realise by a long way such a nicety of deviation of motion as only 1–50th of an inch.

The President observed that at the end of the paper the author had explained what seemed to be an important matter in the

(The President.)
construction of the machine, namely the way in which the grooves in the presser were formed, by constructing them of two cheeks, shaped so that when coming together they left between them a groove of the right shape and width for the hooks to enter while the needles were being depressed. He should be glad to know something also about the construction of the needles, because these seemed to be in a large measure the secret of success. Their importance had been referred to by Mr. Adamson (page 494); and it would be interesting to know how the little groove was made for receiving the point of the beard, and whether in getting rid of the solid metal at that part any considerable amount of trouble was incurred, or whether that little excavation had been made in the same simple way as the grooves in the presser. He asked also what experience there had yet been as to the wear and tear of the machine; because after all an apparatus of that kind would wear out in course of time, although perhaps it might not yet have been worked long enough for any of the parts to show much wear.

Mr. Paget, referring to Mr. Dobson's statement (page 490) that knitting with a single thread would never rival warp-weaving, said this was perfectly correct since the present machine had rendered it possible in warp-weaving to shape fabrics during the weaving. Warp-weaving indeed had hitherto been an absolutely dormant industry in England, almost dormant in France, and but little active in Germany, simply because fabrics so woven could not be shaped during the weaving; and knitting had until now been the only known method of shaping fabrics during the weaving. Now that they could be shaped by warp-weaving, he hoped there would be an increase of that trade. The results given by Professor Kennedy of his observations would doubtless help to explain several points which had not been made quite so clear in the paper as they might have been.

It had been properly and truly remarked by Mr. Adamson (page 495) that high-class delicate machines were an education to the girls who worked them; for an observation of that class of girls, since the year 1854 when he first went to Loughborough, led him to believe

that this was certainly the case; their intelligence was educated by working the machines, and there was no class of operatives so intelligent as those who worked delicate machines involving mechanical contrivance of a high class. The fear had sometimes been entertained that the invention of these knitting and weaving machines might have the effect of taking the bread out of the mouths of the poor girls. There had been three or four generations of these girls since he had been in Loughborough, because, although they took to the trade at the age of fourteen or sixteen, they did not stop long in it; one generation followed another very rapidly, because they generally had high wages, and high wages meant speedy marriages. When he started in Loughborough in 1854, the average wages of the best class of girls occupied in the hosiery manufacture were 8*s.* a week; he paid one 8*s.* 6*d.*, and there were only one or two others in the town receiving the same wages. But in 1885–6, which was a time of prosperous trade, the wages were 19*s.* or 20*s.*; and even at the present time in the hosiery districts of Nottinghamshire, Leicestershire, and Derbyshire, although the trade was certainly slack and the hosiery manufacturers were saying that they were making absolutely no profits, a moderately intelligent girl would not work at this class of work for less than 14*s.* to 16*s.* a week, being double the amount of their wages in 1854. Thus the introduction of such delicate machinery had not only increased the skill and intelligence of the girls, but had also increased their wages and comfort.

The remark made by Mr. Birckel (page 495) respecting the control of the movements to 1-50th of an inch really fell short of the actual fact, inasmuch as the lateral movements of the troughs had to be controlled to 1-500th of an inch on either side of the correct position, making a total extreme range of 1-250th of an inch. The workmen in his shops used as an ordinary tool not only a common old-fashioned pair of callipers, adjusted by tapping to see if the dimension was right, but also habitually Whitworth's measuring machines, which measured 1-10,000th of an inch. Every man and boy who was employed upon the fitting work had to learn to use that machine and to measure to half of 1-10,000th of an inch; and this

(Mr. Paget.)
was done habitually without any difficulty. It was only right that he should express his own acknowledgments to Mr. Whitworth, a former President of this Institution, for inventing such a machine, which enabled such a degree of accuracy to be attained. An examination of the fabrics exhibited would show that a variation of 1-200th of an inch in the motion of the needles would make a sensible difference in the fabric woven.

As illustrating the necessity for the connectors which prevented the main bar and the knocking-over bar from springing apart when the presser-bar came into action, he might recall the fact that even large engine cylinders when bored horizontally had been found on being placed upright to have been bored oval, in consequence of having actually sagged on the boring table to an appreciable extent. Similarly in planing the pressers, if they were planed with the greatest accuracy in the best planing machine, they would nevertheless be fully 1-50th of an inch out of horizontal in the 7 feet width of the weaving machine, simply in consequence of sagging under their own weight. By the addition of the connectors however, connecting the main bar with the knocking-over bar, the two bars were prevented from being sprung apart from each other at any part from one end to the other; whereas without that provision there was no bar of such a length that would not give, with the mere differences of heat, to an extent sufficient to prevent the effective action of the presser.

The needle used in this machine had been invented by William Lee three hundred years ago. Every hosiery machine, whether a warp machine or a knitting machine, depended entirely on these needles. They were made wholly by machinery, except the filing of the point and the bending over of the beard, which were done by hand. The groove into which the beard was pressed, for allowing the loop to pass over it, was made simply by punching the groove in the wire, which had now been done for about twenty-five years past by a machine, instead of by hand as formerly.

In reference to the wear and tear of the machine, only one of these machines had as yet been running for about two months, making samples, in order to ascertain what it could do; and it was not

possible therefore at present to speak positively as to its wear and tear. Inferentially however he could speak confidently, because the presser and the needles and the hooks were the parts on which the chief wear would come; and only recently he had happened to see his first knitting machine, having similar working parts, which had been set to work in 1862, and was still running satisfactorily after twenty-six years' regular work.

The PRESIDENT was sure the Members were highly gratified at having had the pleasure of listening to a paper explaining what was perhaps one of the most beautiful contrivances for replacing in certain kinds of work the Jacquard system of cards. He knew of no comparison that fitted this machine better, producing as it did various patterns and obtaining various changes in such a simple manner as that described, and thus in some cases taking the place of the Jacquard system, which had itself constituted such a great stride in advance of the older methods. He was sure the Members would join in a hearty vote of thanks to the author for his able paper, and for the additional explanations he had given.

ON GAS ENGINES, WITH DESCRIPTION OF THE SIMPLEX ENGINE.

By Mr. EDOUARD DELAMARE-DEBOUTTEVILLE, of Rouen.

Historical.—Nearly a century has elapsed since the first definite description was given of a gas engine; and many years passed before this ingenious idea was developed into a practical working machine. No sooner had the first gas motor been got practically to work than improvements rapidly suggested themselves, and were not long in ensuring success. It is not intended to review the numerous inventions relating to gas engines; but it will be of interest to recall those which have been conspicuous by the importance of their results.

From 31st October 1791, when John Barber published the first description of a gas motor, until 24th January 1860, when Lenoir brought out his well-known engine, thirty-eight patents were taken out in France and elsewhere: and in glancing through these old documents it is surprising to recognise in them all the ideas which are supposed to have originated only yesterday, besides others which may turn out to be the success of tomorrow. Since the later date nearly 700 patents have been taken out, and from an examination of these it would seem as though there were nothing further left to invent; nevertheless each year gives rise to ideas that are new in their application, even if not novel in themselves. Such efforts cannot fail to result in a radical change of the former plans.

Up to 1860 the various inventors may be said to have worked in ignorance of one another's doings, and their designs clearly show that their ideas were original with themselves; their attention was directed not to the improvement of previous inventions, but to the search after combinations which they supposed to be new. But when the first gas engines were got practically to work, the new

ideas followed the current of the time. The inventors who succeeded Lenoir set themselves to improve the double-acting engine; now they are endeavouring to apply the four-stroke cycle of Beau de Rochas. Is this arrangement likely to be final? Will no better plan be discovered for rendering the gas engine a successful rival of the steam engine? As yet it is impossible to answer so intricate a question; but pending some radical change, endeavours can at any rate be made to improve existing gas engines, and to simplify their construction and working. Until very recently the gas engine has been applied especially where only small power is required; its application for such powers as have hitherto been considered the province of steam is reserved for the future. A rapid examination of the most important inventions since 1791 will enable a notion to be formed of what has already been accomplished, and of what still remains to be done.

At that date there were no gas works; and accordingly John Barber described what he considered the best processes for producing the gas. He proposed to distil coal, wood, oil, or other combustible in a retort; and then by means of a pump to inject the gas into a cylinder in which the explosion should take place. A second pump injected air in suitable proportions, and ignition was effected by the flame of a match or candle. To avoid excessive heating, he advised injecting water by a pump. Although his machine could never have been a practical success, it is of interest as representing the first clear idea of an engine driven by explosive gas.

Three years later Robert Street described a gas engine consisting of a cylinder and piston, with a slide-valve containing the flame for igniting the explosive mixture. The mixture was produced by allowing a few drops of oil of turpentine to fall on the bottom of the cylinder, which was superheated by a stove; while the piston, raised by the fly-wheel, sucked in air, which combining with the vapour of turpentine rendered it explosive. The flame in the slide-valve ignited the mixture, whereby the motive power was produced.

William Barnett's invention, dated 18th April 1838, and shown in Fig. 1, Plate 101, marks an important step in the history of

gas engines. He describes three kinds of motor, the first single-acting and the second double-acting, while in the third and most interesting the principle of compression was introduced. In this last, Fig. 1, the gaseous mixture was admitted on both sides of the piston. Two pumps, driven at twice the speed of the motor, compressed the air and the gas separately; and the compressed air and gas were mixed in the cylinder at the beginning of each stroke, and were there ignited. A third pump was used for clearing the cylinder of the burnt gases after their expansion. It is in this arrangement that the advantage of compression is first clearly pointed out; and to this innovation must be added also the novel method of ignition. Recognising the difficulty of igniting an explosive mixture in a state of compression, Barnett proposed to use a cock with a hollow plug containing a gas burner, Figs. 2 and 3. When turned into one position, the port in the plug put the burner into communication with an external flame which lit it; and being then turned rapidly into another position it shut off the communication with the external air, and brought the internal flame into contact with the compressed gas in the cylinder. This mode of conveying the flame certainly could not ensure a regular ignition; but it marks the first step in that direction, and on this account is worthy of notice.

John Reynolds in 1844 proposed an electric battery, the current from which was to heat a platinum wire to incandescence, and thereby cause ignition. A contact-breaker transmitted the current at the instant required.

Shepherd in 1850 used an electro-magnetic machine for igniting the mixture.

Eugène Barsanti and Felix Matteucci in 1857 described an atmospheric motor, the precursor of the well-known Otto and Langen engine, which it closely resembled in external appearance, although from a practical point of view it was by no means all that could be desired. The only detail worthy of notice was the employment of a Bunsen battery, furnished with a De la Rive multiplier, the sparks from which caused the ignition. Subsequently in the Lenoir engine the De la Rive multiplier was replaced by a Ruhmkorff coil.

In 1858 and 1859 Degrand described a whole series of applications of gas engines, and in particular a compression engine in connection with which the four-stroke cycle is mentioned; but unfortunately the mechanical details proposed were not of a practical nature.

Early in 1860, which will always be a memorable year in the history of gas motors, Lenoir produced the first practically successful gas engine: on which account he may be regarded as the inventor of the gas engine. His engine, shown in Fig. 4, Plate 102, is too well known to require description; but it is interesting to remark that in its final form it embodied six successive additions to the original invention; and it is only by following this long course of improvement that the ingenuity of the inventor and the merit of his invention can be duly appreciated. Unfortunately his engine did not realise all the success it deserved; its two chief drawbacks were a defective mode of ignition, and an extravagant consumption of gas.

No sooner had the Lenoir engine become known than it became the subject of lively discussion, not only in regard to its practical advantages and disadvantages, but especially as concerned the scientific conditions of its working. A fresh stimulus was given to inventors, whose efforts were no longer confined to fresh combinations of details more or less novel, but were directed to new conditions of working; and many fresh cycles were proposed, which it would be too lengthy to describe. One specification however is worthy of particular notice, not only on account of its direct bearing on the subject of this paper, but also for the remarkable clearness with which the scientific conditions of a rational mode of working are laid down, and the precision with which the author, Mr. Beau de Rochas, has pointed out in detail the requirements to be fulfilled for attaining the most economical result.

In 1862 Mr. Beau de Rochas published a specification dealing in detail with several scientific questions; the portion only which relates to gas engines will here be summarised as completely as

possible. The theories therein broached have already led to remarkable results in practice, and a more thorough investigation of them will probably be attended by many further improvements. Without noticing the non-compression motor, the arrangement with preliminary compression will at once be considered. Before proceeding to describe the plan by which he proposes to fulfil the conditions theoretically required, Mr. Beau de Rochas lays down four conditions as essentially necessary for realizing the best results from the elastic force of gas:—(1) the cylinders should have the largest capacity possible with the smallest circumferential surface; (2) the speed should be as high as possible; (3) the expansion should be as great as possible; (4) the initial pressure should be as high as possible.

(1) For a given expenditure of gas, the greatest diameter of cylinder will correspond with the most effective utilization of the heat. Wherever possible therefore a single cylinder only should be employed for each individual motor.

(2) But time is a factor in the dissipation of heat. Other things being equal, the slower the speed the greater will be the loss of heat. For the same power a quicker speed means a smaller cylinder; but the antagonism between this and the preceding condition vanishes if it is remembered that for a given expenditure the relation between the stroke and the capacity of the cylinder need not always be the same.

(3) In a gas engine, just as in one actuated by steam or other elastic vapour, the greatest range of expansion gives the best result. But under the conditions already stated the maximum range is limited by the circumstances of each special case. Therefore that arrangement which allows the freest range of expansion, or in other words which permits the earliest cut-off practicable, will prove the most advantageous.

(4) Lastly, the utilisation of the elastic force of gas depends on another element connected with the advantage of great expansion. This element is the pressure, which for the best result should be as high as possible. It is evident that the case here dealt with is one of expansion in a heated state following after compression in a

cold state, or of prolonging the expansion by a method inverse to that which consists in creating a vacuum: such an inverse method would not be applicable to steam, since all compression must involve a corresponding condensation, so that, even if steam were combustible, instantaneous heating would thereby be rendered impossible.

The fundamental idea of Mr. Beau de Rochas is thus clearly seen to consist in the compression of the gaseous mixture to the greatest extent practicable before ignition. Manifestly the only practical way to do this is to use a single cylinder, first on account of the advantage of having as large a one as possible, and next in order to minimise the resistances of the mixture. As a natural consequence, for either end of the cylinder, the following sequence of operations should take place during four consecutive strokes:—*a*, drawing in the gaseous mixture during an entire (forward) stroke; *b*, compression during the second (return) stroke; *c*, ignition at the dead point, and expansion during the third (forward) stroke; *d*, expulsion of the burnt gas during the fourth (return) stroke. Such an engine, he is of opinion, evidently fulfils the condition of the largest possible cylinder, as well as the still more important condition of preliminary compression. Moreover the speed of the piston is the greatest possible in proportion to its diameter, since the work which would otherwise be performed in two strokes is accomplished in only one.

In 1863 Mr. Hugon brought out a motor, in which ignition was effected by a gas flame conveyed by the slide-valve; the arrangement was ingenious, but the motor had only a moderate success.

In 1867 at the Paris Exhibition Messrs. Otto and Langen produced their atmospheric motor, Fig. 5, Plate 103, which bore a strong resemblance to that of Barsanti and Matteucci. Its construction was good, and its working a practical success. The rack and clutch motion was worthy of special notice, the slide-valve was ingenious, and the economy of consumption was considerable; but its working was both noisy and violent. A description of this engine was given to the Institution in 1875 (Proceedings, page 191).

The Bisschop motor, Figs. 7 to 11, Plate 104, appeared in 1870, but its success was confined to engines of very small power, of which a large number were made. It would probably have been still more extensively adopted, had it not been for the Otto engine, which was brought out six years later, in 1876.

Dr. Otto's inventions were two: the first in 1876 related to two kinds of engine, one without compression and the other with; the second in 1877 had reference to improvements in the slide-valve of the compression engine and to other details. The compression engine alone will here be considered, inasmuch as at the present time the non-compressing engine may be regarded as abandoned, on account of its excessive consumption. The fundamental idea of the engine is based on the four-stroke cycle of Mr. Beau de Rochas, already described. In connection with his 1876 invention, Dr. Otto enunciated a theory of the stratification of the charge in three layers. In this stratified condition the charge was imagined to be composed, firstly, of a layer comprising the products of combustion from the preceding stroke; secondly, of a layer of pure air allowed to enter at the commencement of the admission; and thirdly, of a combustible mixture of air and gas admitted afterwards. According to the theory, this stratified charge resulted in a less violent explosion, a successive combustion of one molecule after another, more regular and more silent working, and great economy in consumption. Although the theory might, owing to the then limited knowledge of the subject, be accepted at that time, it can no longer be maintained, as its fallacy is demonstrated by every-day practice. But though from a scientific point of view Dr. Otto was not fortunate, from a practical point few inventors have achieved so decided a success, and for many years he was the only maker of gas engines.

The Otto engine, Fig. 12, Plate 105, is so well known to engineers that any detailed description, beyond the general fact that it is a single-acting motor on the principle of the four-stroke cycle, would be superfluous. But the method adopted in 1877 for igniting the combustible mixture appears to require noticing; and a critical

examination of this, and of the principal methods previously used, seems indispensable, inasmuch as the improvements introduced by the author had their origin in such an investigation.

Ignition.—The arrangement for ignition in the Otto engine is shown in Figs. 13 to 20, Plate 106. In the slide-valve cover is an external flame at F, Figs. 13 and 14; and through the back end of the horizontal cylinder is pierced a port P, Fig. 20, for first admitting the gaseous mixture and afterwards igniting it. Above the port there is also a small hole J, through which an equilibrium of pressure is established between the gaseous mixture in the cylinder and that in the firing cavity C, which is formed in the middle of the length of the slide-valve, Figs. 16 to 19. In the end of the slide-valve furthest from the external flame F is a mixing chamber M, in which the gas and air become intimately mixed as they pass through it into the cylinder port P. By a special arrangement the firing cavity C is charged with a mixture of air and gas in suitable proportions; the slide-valve then begins its stroke, and brings the firing cavity to the external gas-burner F, by which the charge it contains is ignited. The valve being worked by a connecting-rod from a crank-pin, the flame inside its cavity is carried forwards quickly, to be communicated to the compressed mixture in the cylinder, the communication with the outer air being cut off by the same movement of the valve, so that the flame in its cavity is not exposed to any external influence.

If this momentary flame were at once brought into contact with the compressed mixture, it would be blown out by the violent current set up by the rush of the mixture into the firing cavity; but this is avoided by an ingenious arrangement. The small hole J in the cylinder face, Fig. 20, Plate 106, is slightly in advance of the port proper, so that it comes line and line with a similar hole E in the valve itself, Figs. 16 to 18, before the firing cavity C reaches the port P. The hole E goes through into the firing cavity C, so that a minute volume of the compressed gases from the cylinder entering thereby into the larger space of the cavity becomes partially expanded, and revives the flame just dying out. At this instant the

edge of the slide cavity comes line and line with that of the cylinder port; and as the pressure of the ignited mixture in the firing cavity C has thus been gradually increased considerably, there is no fear of its flame being extinguished, or failing to ignite the charge in the cylinder. As an additional precaution, the cylinder port is made of a special shape, and is filled beforehand with a mixture richer in gas; and it is by this richer mixture, containing none of the products of combustion from the previous stroke, that the firing flame is revived inside the cavity C in the slide-valve.

The plan just described is very complicated; it depends on numerous orifices which become rapidly incrusted, owing to the flame that fills them at the moment of ignition; a layer of carbon is deposited on their walls, and soon attains a considerable thickness. To ensure the equilibrium of pressure with sufficient nicety, the setting of the slide-valve must be adjusted to less than a hundredth of an inch; and however well the valve may work at first, it is soon affected by the deposit, and must be frequently cleaned, if the best working is to be maintained. Moreover, being so much reduced in substance at the firing cavity, the slide-valve is easily buckled by the heat of the flame inside it, and its working is thereby impaired. The slide itself gets very hot, and the flame both inside and outside burns up the oil on the rubbing faces, and the combination of these two defects causes frequent seizing. Considering the nicety of the operation of transporting a flame in so confined a space, it is not surprising that, however accurate may have been the original construction and adjustment, misfires are of pretty frequent occurrence, arising either from failure to ignite at the outside burner, or from premature extinction of the inside flame, or from absence of perfect equilibrium of pressure at the required moment; and these misfires must correspondingly diminish the power of the engine. When a rich gas is employed, such as is supplied in towns, the ignition dependent upon equilibrium of pressure is tolerably regular, because such gas is easy to light; but with a poor gas the problem becomes more difficult, and for this reason the use of poor gas has not made much progress. A much stronger flame is required to effect with

certainty the ignition of a poor mixture. With a large engine, starting becomes an operation of great nicety when the flame has to be conveyed, because if the slide-valve does not travel with sufficient rapidity the flame inside it is burnt out before reaching the charge in the cylinder; and it is no easy matter to impart sufficient initial velocity to a fly-wheel of any considerable weight.

An examination of Lenoir's mode of ignition in 1860, which has since been repeatedly copied, discloses still more serious defects; and these defects were obvious from the first, inasmuch as all subsequent inventors, including even Dr. Otto, have been compelled to adopt an actual flame as more certain and less troublesome. In Lenoir's method an insulator containing a platinum wire was fixed at each end of the cylinder, and another platinum wire was fixed inside the cylinder, with its extremity at a short distance from the first. The two wires were connected respectively with the positive and the negative pole of a Ruhmkorff coil, to which a battery sent its current; on the circuit being completed by a key at the proper moment, a spark passed from point to point, and the mixture was fired. The current was then interrupted, and was again sent to the coil in the next revolution of the engine. At first sight this may appear an excellent plan, but it is not found to work well in practice. The following is what takes place:—on first starting there occurs a condensation of aqueous vapour, while the metal is taking up heat; the platinum points inside the cylinder become covered with moisture, and the spark passes only at intervals, or even not at all, thereby causing difficulty in starting and irregularity in running. Moreover while running the points may become coated with the oil used for lubrication, when the same defective ignition is the result. And immersed as they are in the explosive mixture, the points become speedily coated with carbon, and the current is intercepted.

Another cause of irregularity occurs in the interruptor itself, as follows. If it could be arranged that the mixture should be ignited only at the exact moment of the key actually touching the plate, the ignition would be regular; but it is well known that the current

which has passed through the coil becomes so intensified as to begin passing between the key and the plate at as much as nearly $\frac{3}{4}$-inch distance, thereby causing ignition at irregular periods. To avoid this as far as possible, interruptors acting suddenly are resorted to; but these wear out rapidly, and are always rather complicated. At first sight this might seem to be a minor objection, as it might be thought that a variation in the moment of ignition corresponding with a distance of less than $\frac{3}{4}$-inch between the points of contact would be of no practical account; but a comparison of diagrams taken with these variations in the time of ignition shows how widely they differ: it is surprising to note the difference in the indicated power when the moment of ignition varies by even so little as 1-20th of a second. There is also the liability to an accident which the author has twice met with in his early trials: one pole—say the negative—is in direct connection with the engine frame, the whole of which is therefore negatively electrified; and it may happen at any moment that, although the communication with the positive pole has not been made, a spark may pass between the points, and ignite the mixture prematurely before the crank has passed the centre.

A course of practical experiments on the various modes of ignition has shown the full importance of a good ignition. For certainty of working, it is indispensable to have an absolutely certain ignition, powerful enough to explode a poor gas, and free from the numerous objections already indicated. As a matter of fact the only two methods of ignition are by an actual flame and by electricity; the choice is therefore confined to the various applications of these two methods. A powerful ignition is the requirement of greatest importance, and this is completely realised only by the electric spark. All other modes of ignition by flame have proved inferior to it, including alike the heating of a platinum wire by a flame, and the plan of raising a thin tube to a red heat.

The latter is an old plan which was carefully described by Mr. Leo Funck in March 1879, and is shown in Fig. 6, Plate 103; it gives a pretty regular ignition, but is not free from inconveniences, the chief of which is that the heat of the tube never equals the igniting power of the electric spark, and the plan is consequently

not so applicable where poor gases are used, while the tubes themselves deteriorate so rapidly that they last only a few hours. Their wear is the result of the high pressure produced within the cylinder at the moment of ignition, when the white-hot tube is exposed externally to atmospheric pressure only; the compressed gas is admitted inside the tube, and a still higher pressure, tending to burst the tube, is produced by ignition. If, to avoid this, the tube is made thicker, it does not attain the white heat requisite for good ignition. Moreover the tube is cooled by the partial expansion of the compressed gas admitted to its interior, and this cooling still further reduces the chances of a good ignition.

If a valve is employed to regulate the moment of ignition within the tube, there is the further risk of a premature explosion, tending to reverse the direction of revolution of the fly-wheel. This might result from the valve not bearing properly on its seat at any moment, thereby allowing the passage of a thin stream of compressed gas, which would be prematurely ignited.

It might appear that the ill effect of the difference between the internal and external pressures could be avoided simply by placing the tube inside the cylinder; but this would entail even greater objections. The tube holder would have to be removed, whenever it had become incrusted from being situated in the midst of the exploded gas; it would suffer rapid deterioration from the high internal temperature; there would always be the fear of premature explosions; and with this arrangement, after every stoppage an independent method of ignition would be necessary until the internal tube had been brought to a white heat, thus involving two methods instead of one.

The use of a platinum wire heated to incandescence by an electric current still remains to be considered. As in the case of the hollow tube just described, the wire is attended with the disadvantage of cooling at the moment of the introduction of the gaseous mixture, and it is consequently irregular in firing. Even without this fault, it is easy to see that the heating power of a wire raised to a white heat must be inferior to that of a strong spark, which is not affected either by cooling action or by violent currents of air.

SIMPLEX ENGINE.

The Simplex engine, shown in Figs. 21 to 33, Plates 107 to 111, invented by the author and Mr. Léon Malandin, was brought out in 1884. It is on the plan of the four-stroke cycle of Beau de Rochas, and its working is in the main so far the same as that described by him as to dispense with the need of any general description. It will suffice to examine the several novel details which it presents as compared with its predecessors, in regard to mode of ignition, gas mixing, governing, starting, working with petroleum vapour, and with poor gas.

Mode of Ignition.—During the investigations and experiments undertaken for the purpose of deciding upon the general arrangement of the new motor, practical trials were made of all the known modes of ignition; and the conviction was soon arrived at that the electric spark afforded the only satisfactory and economical means of ensuring explosion. But as none of the previous modes of ignition by this means had given thoroughly successful results, the plan was devised of substituting for a single electric spark, produced by contact at a given moment, an uninterrupted stream of sparks, forming practically one continuous spark, and playing within the thickness of the slide-valve itself. The advantage of this arrangement was that the moment of ignition was regulated by the edges of the ports; and at first it appeared strange that this device had not been hit upon by previous inventors; but as soon as ever the difficulties of carrying it out were encountered, the wonder was speedily dispelled. For with the insulated platinum wires terminating in a chamber inside the slide-valve, it was found in practice that, although the ignition from the sparks took place regularly enough so long as the valve was held tight up to the cylinder face, yet whenever from one cause or another the compression inside the cylinder forced the sliding faces apart, the inflammable mixture found its way to the spark prematurely, and the motion of the crank was liable to be reversed. This serious fault was overcome by placing the porcelain insulator in the cover of the valve, as shown in Fig. 29, Plate 111,

which made it impossible for the explosive mixture to reach the spark before the slide-valve had fairly opened communication with the firing chamber C.

One more practical detail still remained to be achieved, namely after each ignition to clear the oblique opening V in the valve and the firing chamber C of the burnt gases, Fig. 29, which would otherwise have mingled with the next charge of explosive mixture, and impaired its explosion. This difficulty has been got over by forming a small oblique vent-hole, at right angles to the length of the oblique firing chamber and communicating from the outer end of the chamber to the slide-valve face, so as to run into one end of a longitudinal groove in the slide, the other end of the groove being open to the outer air. What then takes place is as follows: at the proper moment for ignition, that is to say, when the edges of the oblique passage through the slide-valve and of the admission port in the cylinder come line and line, the compressed mixture expels the burnt gases from the firing chamber through the small vent-hole, and becomes ignited by the continuous stream of sparks playing between the platinum points. The time allowed for this expulsion is about 1-150th of a second; but, owing to the high compression of the explosive mixture, the burnt gases are driven out in even less time, so that their expulsion is perfect, and the instant of ignition is ensured with mathematical punctuality. The advantages of this new mode of ignition are considerable; the slide-valve, which in other gas engines is the part of greatest nicety, becomes as simple as that of a steam engine, being merely a cast-iron plate in one piece without any loose parts, pierced with two holes, one for the admission of the mixture, the other for its ignition. Its maintenance is easy and cheap, and with ordinary attention it will work for more than a year without any repairs. This is a great improvement over the flame-carrying and equilibrium slides, which require to be frequently faced up.

By getting rid of the gas burner and of the conveyed flame, a considerable reduction is effected in the temperature of the valve-chest, lubrication is facilitated, and incrustation is done away with. The high igniting power of the spark allows of a considerably

greater preliminary compression of the explosive mixture, with a corresponding economy in consumption of gas. The certainty of ignition and the high igniting power have been of the greatest advantage in the application of the plan to poor gases. Particulars are hereafter given of some of the trials made with the Simplex engine, from which an idea can be formed of its economical advantages.

Gas mixing.—The air and gas are mixed, not inside the slide-valve, as in the Otto and other motors, but in an external mixing chamber M, Figs. 28 to 30, Plates 110 and 111, fixed on the cover of the slide, the air entering at one side, and the gas through a valve at the other. After meeting and mixing, they are violently sucked into the cylinder by the motion of the piston, through a passage which is at first circular, then conical, and then rectangular; they are thus intimately mingled into a homogeneous mixture. There is nothing particularly original about this arrangement; but it is simple, and the experience of more than four years has shown that it is completely successful in working.

Governing.—The two methods hitherto adopted for regulating the speed in gas motors are: (1) full admission or none—that is to say, the supply of gas is totally cut off for one or more strokes whenever any increase of speed occurs; (2) proportional admission—that is to say, more or less gas is admitted, forming a more or less powerful explosive mixture, accordingly as the engine runs slower or faster. The second method at first sight appears the more rational, but it entails certain inconveniences which have led to its rejection. The stronger or weaker mixture resulting from a proportional admission of gas is liable to become non-explosive, either because it is too rich, or because it is too poor. In either case no ignition takes place, and a charge of gas is expended to no purpose; and under certain conditions this waste may amount to a considerable proportion of the total consumption. For this reason some different arrangement, based on the other principle of full admission or none, was sought for.

Air Governor.—This consists of an air-pump barrel B mounted on the slide-valve S, and moving to and fro with it, Fig. 29, Plate 111; in the barrel is a piston made perfectly air-tight by packing rings. The piston-rod is attached to the cover of the slide-valve, and consequently holds the piston stationary; it is fixed to the piston between two india-rubber washers, which allow of a slight oblique motion when the cover is set up as the slide-valve wears. In the outer closed end of the air-pump barrel is a micrometer screw A with a conical point, by which the hole communicating with the outer air is more or less throttled. Near this end of the air-pump, on its side and at right angles to it, is placed another smaller cylinder J communicating with it at its inner end. In this smaller cylinder moves freely a piston, the rod of which carries at its end a steel knife-edge K. Between the knife-edge and the piston is a spring, tending to keep the piston home; the piston is put in place or removed by means of a bayonet-joint. The knife-edge K controls the valve G for admitting the gas, when the small piston is home at the inner end of the cylinder J.

The action of the governor is as follows. If the engine is running at say 200 revolutions per minute, the slide-valve will be driven at a speed of 100 revolutions, and the large air-pump B will suck and force 100 cylinderfuls of air through the small hole at its extremity. Supposing that the micrometer screw A is adjusted so as to allow only these 100 cylinderfuls of air to escape through the annular space partially closed by its conical point, then so long as the normal speed of 200 revolutions is not exceeded, the smaller piston will remain home in its cylinder J, and the knife-edge K will at each stroke encounter the gas admission-valve and open it to form the explosive mixture. If from any accidental cause the speed of the engine is increased, and the slide-valve makes say 101 revolutions, the air-pump B will suck and force one extra cylinderful of air; and as this cannot escape through the small hole, it will push outwards the smaller piston J with its knife-edge K, as shown dotted, so that the latter will miss the gas valve and fail to open it. No explosive mixture being formed, there will be a misfire, and the speed of the engine will be reduced. This governor

is very sensitive, and will be very advantageous for any future applications of the gas engine to boats or cars, as it works equally well in any position, independent of level.

Pendulum Governor.—For stationary engines another form of governor is recommended, as it is cheaper, and not liable to wear. This governor, shown in Figs. 25 to 28, Plate 110, is based on the principle of the pendulum, but the method of its application is new, the essential novelty being that the pivot of the pendulum is absolutely stationary, and that the pendulum falls by its own weight alone, so that the time of its fall is invariably the same. It is composed of two weights fixed on a rod, in the middle of which is a pivot P. This pivot turns in a forked bearing fixed on the cover of the slide-valve. The heavier weight H is naturally placed at the bottom. The lighter weight L, which is above the bearing, is adjustable by means of two nuts threaded on the upper part of the rod; by raising or lowering this upper weight, the lower weight is balanced to a greater or less extent. In the end of the rod projecting below the lower weight H is a notch N facing the gas valve G. On the slide-valve is fixed a stem carrying a double rocking-arm R with two knife-edges, of which the larger and heavier at a given moment encounters and opens the gas valve, while the smaller and lighter knife-edge is caught in the notch N below the lower weight. A spring on the rocker aids the weight of the larger and heavier knife-edge in tending to depress it below the stem of the gas valve, which it opens only when the arm is brought up into a horizontal position.

The action of this arrangement is as follows. Supposing the normal speed of the slide-valve to be 100 revolutions per minute, the upper weight L, Fig. 25, must be so adjusted as only partially to balance the lower weight H, so that its rate of fall may correspond with that speed. In the back stroke of the slide, Fig. 25, the smaller knife-edge engages with the notch N of the pendulum. Then the slide makes its forward stroke, and the notch being in gear brings the pendulum to bear with all its weight upon the smaller knife-edge, tilting the rocker so that the larger knife-edge becomes horizontal, Fig. 26. The larger knife-edge

encounters the gas valve and opens it, and the explosive mixture is formed. Should the slide travel at a slightly accelerated speed, it will return in a shorter time than before; the smaller knife-edge will miss the notch, Fig. 27, as the pendulum will fall in the same time as before; and its weight will not bear on the rocker, which will remain in an oblique position and fail to open the gas valve; no explosive mixture will be formed, and the engine will slow down to its normal speed. It is evident that this governor is a very sensitive one, as the knife-edge and notch will catch or miss according to the fall of the pendulum, which must occur always in exactly the same time. There is no wear of parts, and the speed is regulated by simply adjusting the upper weight L, which can be done while the engine is running.

Various modes of Starting.—For engines of small size, not exceeding 10 HP., starting is a very easy matter; a turn of the fly-wheel suffices to draw a charge of the explosive mixture into the cylinder and to compress it; ignition then takes place, and the engine starts at once. This statement refers to the Simplex engines, in which ignition is effected as easily at a slow as at a high speed; but with other kinds of engines starting is a more difficult affair. Up to 10 HP. one man can turn the fly-wheel and produce the compression; beyond that power, and in proportion as the engines become larger, the number of men required for starting becomes a serious consideration, and for many years inventors have taxed their brains to discover some practical method of starting. A few of the more important of these methods may be mentioned, but no good purpose would be served by describing them all.

The simplest plan for starting was to store up in a separate receiver, during the time that the engine was running, a sufficient charge of explosive mixture, which when ignited at the proper moment would serve to start the engine. This plan was unfortunately open to two fatal objections: the tightness of the retaining valves could not be ensured, and after a certain time the gas lost its pressure. There was also the risk of serious accidents from the bursting of the vessel containing the compressed explosive

mixture; and the danger from this cause led to the discontinuance of the plan.

Other makers employed the pressure of the exhaust gases. This obviated the danger of bursting the vessels, but the leakage of the valves still remained, and it sometimes happened that just when it was wanted there was no pressure left in the cylinder, and starting was impossible. Compressed air, springs, and other devices of a more or less practical nature were tried; and even a small auxiliary motor was at length adopted as the only reliable plan. This method is effective, but expensive, and for engines of any considerable size it costs as much as an additional engine, besides the peculiarity of employing one engine to start another. For engines of still greater power, the auxiliary engine itself becomes so large as to need another smaller one to start it: so that the whole series would look like a show-card of various sizes of engines.

It is only recently, and after prolonged research, that a practical mode of starting has been worked out; and it is the method of ignition employed which has rendered its adoption easy, and its operation certain. The plan for engines up to 20 HP. will first be described, and afterwards its simplification for engines of larger power.

For an engine of 16 HP., for example, a small gas pipe, Figs. 30 to 33, Plate 111, furnished with a three-way cock T, is fitted on the igniting apparatus; through the plug of the cock is a passage for admitting the gas, and into the same passage is pierced obliquely a small hole communicating with the outer air. An india-rubber tube I, Fig. 30, connects this gas pipe with the gas supply G of the engine; and at the point of junction is placed a small graduated cock, which may be called the gas cock, for regulating the proportion of the explosive mixture. The method of starting is as follows. The engine must previously have been stopped at the ignition point, which is easily done by means of the three-way cock. The induction coil is fitted with a contact-breaker, which interrupts the flow of sparks between the platinum points in the firing chamber C, Fig. 29. When this is done, the three-way cock is first opened, and then the gas cock to the

marked position. The fly-wheel is slowly turned to draw in the explosive mixture, which enters the cylinder through the firing chamber; the gas comes through the india-rubber tube I, and the air through the small oblique hole in the three-way cock. When the piston has made two-thirds of its stroke, the three-way cock and gas cock are closed. Then the large gas cock used when the engine is running is opened to the position convenient for starting. The fly-wheel is turned backwards to compress the charge a little, the current switched on, the spark produced, the charge ignited, and the fly-wheel receives an impulse sufficient to start the engine. For motors up to 20 HP. the slight compression of the charge is necessary because the dead resistances are relatively great. But with larger engines this is not necessary, and the operation is as follows.

On the cylinder is fixed, above the compression chamber, a small pet-cock, forming a communication between the interior of the cylinder and the outer air. The engine must previously have been stopped, not at the point of ignition, but somewhat beyond, with the crank at an angle of 90°, which is easily done as before by means of the three-way cock; the piston has then made about half its stroke. The gas cock is opened to the marked position as before, as is also the three-way cock. As the gas is under slight pressure, it enters the cylinder through the firing chamber, and draws in air with it through the small oblique hole. The explosive mixture thus formed fills gradually the space behind the piston, expelling the burnt gas through the cock on the top of the cylinder, which must be opened previously to that for the admission of the gas. In about a minute the cylinder of a 50-HP. engine is full of explosive gas; and the cylinder cock, the gas cock, and the three-way cock are then closed. As before, the large gas cock is opened to the starting position, the current switched on, the charge ignited, and a sufficient impulse given to the fly-wheel for starting the engine. By this method the large engines which have now been at work more than a year are started with the greatest ease.

Working with Petroleum vapour.—In France, owing to the heavy duty on petroleum and its products, its application to gas engines is

and must be limited; but in the provinces and in districts where there are no gasworks it may be an advantage to get a motive power that can be relied on in working and can be easily managed. An attempt has therefore been made to improve on previous applications of this source of power; and the most recent combination for the purpose is considered to have proved successful.

Previous methods, as is well known, consisted in passing a current of air over volatile liquids, the extent of surface in contact being increased in a variety of ways. The petroleum was passed over porous substances, or was agitated by vanes to facilitate its evaporation. These methods involve the following inconveniences. The liquids employed are of very low density—from 0·650 to 0·700—and are composed of various elements of different densities; consequently the air passing over them becomes at first carburetted by taking up the more volatile constituents, so that the liquid gradually increases in density, and its constituents become more and more difficult of evaporation, until at last a residuum is left which cannot be used and has to be thrown away. The engine, which worked well at first, slows down until it ceases to develop any motive power. In addition, the intense cold caused by the evaporation renders the liquid incapable of saturating the air. This difficulty has been surmounted by applying heat, either to the air before its introduction, or to the liquid itself; but the gradual impoverishment of the liquid still remains an objection.

Another very serious defect accompanied all the methods employed. During the distillation of the petroleum to obtain the light products, a certain proportion of organic and mineral substances was carried over by the vapours given off; and these substances were again taken up in an impalpable form by the air during its passage over the liquid, and when subjected to the high temperatures produced in the slide-valve and cylinder they formed a thick crust, which after a few days not only necessitated a thorough cleaning out, but also affected the moment of ignition by clogging the edges of the ports. The result was equally objectionable, whether a slide-valve was used, or whether the liquid was introduced direct into the

cylinder by spray injectors or pumps: a rapid incrustation took place in either case.

Carburator.—To obviate these defects the arrangement of carburator shown in Fig. 24, Plate 109, has been adopted. A receiver R containing products of low density is placed immediately above a spiral brush B made of hair, which is fixed in a jacketed chamber C heated by hot water from the motor, whereby the refrigeration due to evaporation is neutralised. In the bottom of the receiver is a cock D with a graduated disc, by which the supply of the liquid is regulated according to the consumption of the engine. Close to this cock is another, supplying the hot water that comes from the cooling jacket of the engine; and this water, at a temperature of about 50° centig. (122° Fahr.), mixes intimately with the petroleum liquid, which it carries along with it in its fall on to the brush B; and by the time that it reaches the lower receiver L the complete evaporation of the light products has been effected. A safety-valve S, through which the gas is taken off to the motor, prevents the ignition from extending backwards. It might be thought that the water would absorb part of the light products, and so cause a considerable loss; but this is not the case, and experience shows that the whole of the petroleum is volatilized. The only constituents absorbed by the water are the mineral and vegetable substances previously mentioned; and all incrustation from this cause is therefore completely prevented. After several months' working, the engine is in as good condition as on the first day. Moreover there is no fear of gradual impoverishment of the liquid, as the whole of the volatile constituents are evaporated from each portion as it flows through the chamber C; so that the working of the engine is always regular from beginning to end, and the power given off is always the same.

Engine Trials.—The Simplex engine has been tested with the following gases:—coal gas, Dowson gas, gas from the Lencauchez generators, petroleum vapour, wood gas; and with all of them it works equally well. In spite of the high initial pressure to which

the explosive mixture is subjected, the working is smooth and noiseless. This result is attained by delaying the ignition, so that it shall occur not at the dead point, as proposed by Beau de Rochas, but somewhat later, when the piston has already made part of its forward stroke. At first sight it might be supposed that this would entail a loss of power; but experience shows that, though the area of the indicator diagram is diminished, the work measured by the friction brake is greater. Starting is also rendered easier by this method of working.

The application of gas engines for driving dynamos has often led to fallacious results, and thus far cannot be said to have been a success. It must be acknowledged that in most installations, especially those on the incandescent plan, the light has not been steady, but has flickered so disagreeably as to be trying to the eyes. On this account the use of gas engines for lighting purposes has been restricted, although naturally there should be a large field for their employment in that direction. It has been sought to remedy this defect by employing a two-cylinder engine and a countershaft, with fly-wheels on both countershaft and dynamo. The evil is thus diminished, but at the needless expense of higher first-cost, larger space, and a more complicated engine; for a better result may be obtained by simpler and cheaper means. Several months' experience at Mr. T. Powell's works in Rouen has shown conclusively that a gas engine with a single cylinder, driving direct a dynamo placed as close as possible to the fly-wheel, gives a better result than the complicated arrangement above described.

This plan can easily be tried practically. All that is required is, first to drive a dynamo in close proximity, trusting to the normal slip of the belt to minimise the jerks, and then to drive it at a considerable distance. A marked advantage, which seems easy of explanation, will be found to result from the first plan. With short belts the shock of the explosion is not communicated to the dynamo; but on the other hand by driving at a long distance the shock increases the whipping of the belt, and transmits an amplified jerk to the dynamo. It is sometimes thought that the slip of the belt causes a loss of power; but the author is not of this opinion,

as he has found by trial that the number of lamps lighted per horse-power per hour is as great when driving at a short as at a long distance. But even admitting that there may be a slight loss of power, it is certainly less than that resulting from the use of a countershaft, which, as demonstrated by recent experiments in the United States, may amount in some cases to as much as 20 per cent. of the power developed by the engine.

Tests of Consumption.—Trials were carried out on the 7th and 8th November 1885, by Dr. Aimé Witz, of Lille. Leading dimensions of the engine :—diameter of cylinder, $7\frac{7}{8}$ inches; stroke, $15\frac{3}{4}$ inches; speed, 160 revolutions per minute. The effective work given off by the motor was measured by a Prony brake, the arrangement being that adopted by Messrs. Steward and Brooks. The town gas contained about 5,400 calories per cubic mètre (about 607 heat-units per cubic foot) at constant volume; the Dowson gas, comparatively rich in carbonic oxide, about one-fourth of that quantity. Mean pressure of the town gas, 20 millimètres (0·79 inch) of water; of the Dowson gas, 55 millimètres (2·17 inch).

7th November 1885. Duration of first trial, 1 hour; effective HP., 6·70; consumption of town gas per effective HP. per hour, 22·09 cubic feet; reduced to 0° centig. and 760 mm. barometer, or 32° Fahr. and 30 ins. barometer, consumption 21·55 cubic feet; water per effective HP. per hour, 4·80 gallons; temperature, entering 51°, effluent 135° Fahr. Duration of second trial, 2 hours; effective HP., 8·67; consumption, 20·66 and 20·12 cubic feet; water per effective HP. per hour, 4·44 gallons; temperatures, 51° and 165° Fahr. Duration of third trial, 1 hour; HP., 9·28; consumption, 21·23 and 20·73 cubic feet; water, 4·37 gallons; temperatures, 50° and 172° Fahr.

8th November 1885. Dowson gas. Duration of first trial, 2 hours; HP., 7·12; consumption, 90·14 and 88·03 cubic feet; water, 5·82 gallons; temperatures, 48° and 144° Fahr. Duration of second trial, 30 minutes; HP., 3·61; consumption, 118·14 and 114·85 cubic feet. Duration of third trial, 30 minutes; HP., 5·26; consumption, 100·71 and 97·88 cubic feet; consumption of Moehring oil, 5·64 oz. per hour.

Other trials of the Simplex motor have given the following results. A 50-HP. engine, working with a load of 35 to 40 effective HP., consumes daily, with a Dowson generator rather too small, 51 lbs. of English anthracite coal per hour, equivalent to a consumption of from 1·475 to 1·296 lb. per effective HP. per hour, inclusive of everything. A 16-HP. engine, supplied with coal gas and working with a load of 12 effective HP., uses 2,300 cubic feet per day of 10 hours, or say 19·4 cubic feet per effective HP. per hour. These two engines are in constant work, and their consumption is ascertained from the daily records kept for several months, and not from experiments.

From the low consumption obtained by the use of poor gases, a considerable development of the manufacture of large gas engines may safely be predicted; for their consumption is more economical than that of the best steam engines. This has now been conclusively proved.

In the foregoing rapid sketch, engines of types other than those of Lenoir and Beau de Rochas have been passed over, since the principles of their construction were not those from which the Simplex engine has been worked out. A more complete description of these principles would have required a whole treatise, and would have been beyond the scope of the present paper. Those who desire to go deeper into this matter may be referred to the works of the distinguished men of science whose researches have done so much to promote the development of the gas engine. The author must acknowledge his obligations to the important works of Mr. Aimé Witz, by whose theories he has been constantly guided in his investigations; and also to the writings of Messrs. Dugald Clerk, R. Schöttler, and Gustave Richard, which are the most complete of all that have appeared upon this subject.

A study of all the patents which have been taken out for gas engines, although a laborious task, will doubtless be undertaken at some future time, and will prove not only interesting but materially useful to those who have set themselves to accomplish the triumph of the gas motor over its rival the steam engine.

Discussion.

Mr. J. Macfarlane Gray had visited the works in Rouen where the Simplex gas engine was to be seen, and had been much interested in its working. The plan of putting the dynamo near the fly-wheel of the engine, so as to take advantage of the slip of the belt for getting over irregularities of speed (page 522), seemed to work well, for he had not been able to detect the slightest fluctuation in the burning of the lights; but he should think there would be some wear and tear in consequence of the slipping of the belt. The engine he thought was well designed and simple, especially the pendulum governor (page 516), which worked beautifully. It was not absolutely new, he understood, but he had not seen it before. He had watched its working for some time, and thought the plan of controlling the engine by the movement of the pendulum was a beautiful arrangement.

The President said the paper, after elucidating the development of gas engines from early times to the present, appeared to show the necessity of two things. The first was that there should be a compression of the explosive mixture of gas and air before the explosion was actually accomplished; this seemed to be established beyond question in the course of the history of gas motors. And it furthermore appeared that there should be four distinct operations in the cycle of work:—the drawing in of the gas, the compression of the gas, the explosion at or near the dead point, and the subsequent expulsion of the exploded gas after it had done its work. It seemed to him that although Mr. Otto had proceeded on a fallacious supposition in reference to the necessity for three successive layers in the composition of the explosive charge, as pointed out in the paper (page 506), he had nevertheless been able to base upon it considerable improvements in the working of gas engines. The second point to be noticed seemed to be that the old system of igniting by the presence of a flame, which had to be lighted every time the explosion came round, and then to be popped into the compressed gas so as to ignite it afresh every time, had led frequently

(The President.)
to misfires, and had now been successfully replaced by the electric spark; and it seemed to be a settled point that it was by the aid of the electric spark that the explosions must be accomplished. There thus seemed to be two necessary conditions for the success of the gas engine:—the compression of the explosive materials, and their ignition by the electric spark.

Mr. M. Holroyd Smith thought the first part of the paper, which gave a review of the past history of gas engines and led up to the Simplex engine, was valuable in one respect, because it showed that the original conception of the cycle of movements was due to Mr. Beau de Rochas (page 505). But he considered the paper fell short in the comparisons it drew, where dealing, apart from the Otto engine, with modern gas engines in England, such as might fairly compete with the Simplex. In this engine two things were claimed as novelties. One was the means of obtaining a uniform speed of the dynamo, by taking advantage of the slip of a short belt; that, according to his own experience, was an old method. The other was the employment of the electric spark for the ignition of gas. Was it or was it not wise to use an extraneous means for effecting the ignition, when there was the possibility of igniting without extraneous means? While far from wishing to say anything against the employment of electricity in any direction in which it could possibly be used, he considered it was necessary to look at the question from the point of view of what was best for the user. No details had been given as to the source of electricity in the gas engine; was it derived from a battery or from a dynamo? Eighteen months ago he had seen an engine worked by gas, where the ignition was by electricity produced from a little dynamo, which was placed at the side on the frame-work of the engine, and received its motion from the fly-wheel. There was an ingenious contrivance for disconnecting the dynamo from the fly-wheel, and coupling it to a large pulley for working it by hand just when the fly-wheel was being turned round for getting a start: so that a high initial speed was obtained for the dynamo, in order to produce the necessary flash. As soon as the engine had got fairly started, the dynamo was put

into another relation of speed for producing the sparks. Thus the dynamo was enabled at first to generate during the slow movement of the fly-wheel a sufficiently strong spark for ignition ; and afterwards, when the engine was up to its full speed, it was prevented from over-running the dynamo. It was an ingenious idea, and he believed the engine went under the name of the Baldwin, and was made by the firm of Otis Brothers who had made one of the three lifts in the Eiffel tower.

The PRESIDENT said that engine was to be seen in the Exhibition at the present time.

Mr. SMITH said the reason of his asking about the source of electricity in the Simplex engine was that, if it depended upon a battery, it was not reliable. In that case, instead of a simplex engine, was it not really a complex engine that was now being introduced? because there were here two elements at work—electricity and gas—for producing power, instead of relying on the gas alone. The introduction of electricity was upon the supposition that the flame was not to be relied upon. Exception to that statement he thought would be taken, not only by Messrs. Crossley but also by other makers of gas engines.

Another point that seemed to him objectionable in the new engine was the slide. The majority of gas engines depended upon the slide moving to and fro; and it had always to move, whether work was being done or not. In the "Forward" gas engine, made by Messrs. Barker of Birmingham, which had come under his notice a short time ago, the slide was entirely dispensed with; and the engine was governed, not by either alone of the two means mentioned in the paper—namely the strength of the mixture, and the number of impulses—but by both of these combined. The adoption of this plan had the advantage that it could give either a frequent strong charge and an occasional light charge, or an occasional strong charge and a frequent light charge, as occasion demanded; and the result was satisfactory. In the drawings of the Simplex engine he did not see anything to show precisely the

(Mr. M. Holroyd Smith.)

exhaust arrangement; he supposed the engine did not exhaust through the same valve through which it received the feed. In the Forward engine the feed valve was at the side of the cylinder, and there was a separate and distinct ignition chamber at the back end of the cylinder. The exhaust and feed were worked by a cam arrangement something like a trip action, instead of by the ordinary slide action. The ignition valve at the back end of the cylinder was a circular disc, having eight radial slots through it; and round its circumference were eight ratchet-teeth, for rotating it in one direction only. A paul controlled by the governor caught the teeth on the disc, and moved it round through one tooth every time the ignition was required. The cam action was also controlled by the governor, so that the governor was at the same time controlling both the feed valve and the ignition valve; and the latter moved only when ignition was required. Wear and tear therefore were saved, inasmuch as the lower half of the rotating disc was exposed to the open air, and thus the disc never got hot; and it was only a small amount of movement that occurred when ignition was required, namely one-eighth of a revolution. The beauty of the engine lay in the fact that the governor controlled both the degree of mixture and also the number of impulses; and unless both the mixture and the impulse were required, there was no movement either of the valve that governed the admission of the gas, or of the valve that caused the ignition of the mixture. As an example how useful that process of regulation was to electrical engineers, he mentioned a test he had made to prove the steadiness of running. A simple 4 HP. engine, loaded up to about 6 HP. with a Prony brake, had been driven at full speed. Instead of taking one minute as the unit of time for counting the revolutions, he had taken only ten seconds, during which the revolutions of the engine were carefully counted. With the stroke of a hammer the whole load was then suddenly thrown off; and in the next ten seconds the revolutions were again carefully counted. With that sudden test upon the engine, the variation in speed was only 0·02 revolution during the period of ten seconds. While therefore he was pleased to see the excellent gas engines produced in France, he wished

to show that English engineers also were not content with what had been done in the past, but were still going forward, and he believed were showing equally good results.

Mr. William Walker was of opinion that the introduction of the electric spark for ignition was a step in the right direction; and he thought it would come into common use, although it had not yet been much used in England.

Professor Alexander B. W. Kennedy, Member of Council, said there were in England, besides the Forward engine mentioned by Mr. Holroyd Smith, at least half a dozen gas engines, such as the Otto, Beck, Atkinson, Griffin, and others, which might fairly be put in the front rank, and might have been compared, as well as those mentioned in the paper, with the pretty little Simplex engines working in the Exhibition. Naturally enough every inventor thought his own production better than others; and an allowance might therefore be made for conclusions arrived at in a historical investigation of the kind given in the paper just read.

The igniting tube appeared in page 510 to be thrown aside as unsatisfactory, notwithstanding that some of the principal gas-engine makers were continuing to use it, and were satisfied with its success. They had recognised that it might even have to be changed after 24 hours' working, he believed; but it could hardly be thrown overboard on that account. It was used in the Atkinson or Cycle engine, and in the Otto engine which had recently been brought before the Society of Arts for trial; * and it was therefore obviously a thing to be seriously considered.

With reference to governing (page 514), the compound plan described by Mr. Holroyd Smith (page 527) as employed in the Forward engine appeared certainly a rational and proper method. Within certain limits of strength of charge the governing took place by diluting or intensifying it; but beyond a certain degree of strength in either direction it would fail to be exploded. If the whole work

* Society of Arts Journal, 15 February 1889, pages 216-218.

(Professor A. B. W. Kennedy.)
was thrown off the engine, for instance, the charge would have to be so much diluted, in order only just to keep it going, that it would fail to explode. Beyond certain limits therefore the engine was governed by the hit-and-miss method; but within ordinary limits of working, say up to a variation of 20 or 30 per cent. in the resistance, the governor acted by diluting the charge. That was certainly the case in the Beck engine, if not in the others, and it seemed to be a rational and successful way of governing. The fall of the pendulum in the governor of the Simplex engine (page 516) was a very pretty action, governing the engine by just catching or failing to catch the rocker actuating the gas valve. It would be noticed that whenever the pendulum did catch the rocker, the centre of suspension of the pendulum was thrown up a little in its bearings; and provision was made for this slight lift by letting the centre of suspension work in a notch in which it could rise, instead of in an eye. The Members he hoped would make a point of seeing the working of the governor on the engine shown in the Exhibition, for it was a very ingenious device. The starting arrangement described in page 518 looked most promising; the importance of a good means of starting was well known, and if this one were as successful as it seemed to be, it would form one of the most important steps yet made in improving the gas engine.

In connection with the brake horse-power in the engine trials referred to in page 522, having made experiments himself he should have liked to see indicator diagrams. The statement made in page 522 he understood to amount to this: that by delaying the ignition, and thus getting what would ordinarily be regarded as a worse indicator diagram, it was found possible to save so much friction, by not having the full pressure on right at the commencement of the stroke, that a better result in brake horse-power could actually be obtained. That was an interesting statement, respecting which he should much like to have more particulars. (See Plate 112 since added.)

In reference to the Lenoir engine, mentioned in page 503, some of the earliest experiments with gas engines, if he remembered rightly, had been made by M. Tresca with the Lenoir engine in the

adjoining hall many years ago; so that the Conservatoire des Arts et Métiers was historically connected with the development of the gas engine.

Mr. W. H. Maw had had the opportunity during the previous week of seeing the gas engines exhibited by Messrs. Crossley at the Windsor show of the Royal Agricultural Society, and they were without exception fitted with the incandescent tube for ignition. He understood from the makers that they were abandoning the plan described in the paper of ignition by means of an open flame carried in through the slide-valve, and were now altering their patterns: so that it was only a question of time how soon all their engines would be fitted with the incandescent tube.

Mr. Gisbert Kapp said that, when a dynamo was spoken of as a means of producing electricity for ignition, what was generally understood to be meant was a rotary dynamo which must run at a high speed. If it was driven from the engine in the usual way, so that when the engine was running at its regular speed the dynamo might go at the requisite speed for producing the igniting sparks, it was clear that it could not be driven at that speed when the engine was first started by hand. But he had seen at the Exhibition in connection with a petroleum engine an ingenious arrangement, to which he wished to draw attention, consisting of a kind of dynamo that did not rotate, but only oscillated. An armature between permanent magnets was connected with a spring, and by the motion of the fly-wheel it was drawn over by a lever through an angle of perhaps 90°, and then released by a trigger. On its release the armature flew back with a motion which was so quick that, though the fly-wheel might be turned but slowly, it was quite sufficient to give the spark for ignition.

Mr. Henry Shield considered a dynamo was not in the least degree necessary for a gas engine. The engines that he had had to do with, having an igniting tube, had some of them worked a fortnight without changing the tube; and when the tube was

(Mr. Henry Shield.)

properly fitted into the engine, any attendant of the slightest intelligence could see at once whether it was beginning to fail at the particular place at which it was most likely to go. Practically there had not been the slightest difficulty with the igniting tube.

The President asked how the engine was started with the igniting tube.

Mr. Shield replied that the tube was always lighted beforehand for starting the engine.

Mr. W. Worby Beaumont said that Fig. 6, Plate 103, showed how the tube could be heated for ignition before starting. Concerning the methods of ignition he should like to mention one or two things. Many years ago he remembered a number of Lenoir gas engines being made at the Reading Iron Works, some of which worked well for a little time, but most of them worked badly afterwards and were converted into steam engines; and the manufacture of the gas engines was ultimately given up at those works. At that time a battery was used in the works for experimental tests of the engines; but similar batteries and induction coils, when sent away to the establishments of those who bought the gas engines, soon became practically troublesome; and he believed it was the case even now that, when electrodes were used as a means of igniting gas or petroleum vapour, difficulty was experienced from corrosion and incrustation; he should therefore like to know why in the Simplex engine the author had found it desirable to return to the Lenoir idea, and explode by a spark. He seemed indeed to have got an ingenious arrangement for effecting that object; but remembering the experience in England, and remembering what the gas-engine makers with large experience were now doing, the question was whether any result was arrived at superior to that arrived at by English makers, and was it arrived at in a cheaper or better way in any respect. It was said that igniting tubes were now being generally used; even the most cautious makers, who had long been using the slide-valve and

admitting a little flame through it, were now attaching the tubes, which he believed had first been practically used in Atkinson's differential engine. The engines running with the incandescent tubes he believed had never failed. In many cases the tubes had lasted for several weeks, generally for a fortnight. Their cost was only a few pence, and they were renewed by simply unscrewing them at the back end of the cylinder. Another advantage of the igniting tube was that, by placing it in a chimney which surrounded the heating flame and the tube, and by attaching the chimney so that it could be placed higher or lower, so as to cover less or more of the length of the ignition tube, the position of the hottest part of the tube was altered, whereby the period of ignition might be altered, and with certainty. This he thought would explain the simplicity and value of the ignition tube, and the reason for its general adoption since its introduction by Mr. Atkinson.

The President asked in what way it was supposed the period of explosion was varied. Was it meant that according to the intensity of the heat imparted to the ignition tube the moment of explosion could be delayed, because of the mixture having to lie longer in contact with the cooler surface before it exploded?

Mr. Beaumont replied that the explosive mixture in the gas-engine cylinder was forced into the little closed ignition tube, which was heated to incandescence. The ignition of the gas did not take place until the compression had produced a certain degree of pressure in the cylinder. The length of the tube had to be determined for the particular size of the cylinder. The tube usually stood out something like 7 inches from the inside of the cylinder, and the position of the incandescent part would affect the period at which the ignition would take place. If the incandescent part was brought an inch further away from the cylinder, then the ignition would take place a little later. The amount of variation in the moment of ignition was required to be only very small indeed; so that all the variation that was necessary was obtained by this simple means.

Mr. JEREMIAH HEAD, Past-President, desired further information about the dual mode of governing a gas engine, described by Mr. Holroyd Smith (page 527), by affecting both the number of impulses per minute and also the explosive mixture. He wanted to know whether the relative proportion of air and gas in the explosive mixture was altered, or merely the total quantity of the two with one constant proportion. If the proportion of gas to air was altered, he should like to know whether or not any inconvenience resulted therefrom; because, as was well known, a given weight of gas of a certain standard quality required a certain definite weight of oxygen for its complete combustion. If there was too much air, it appeared to him that there would be a risk of failure to explode; while if there was too little, what was exhausted from the cylinder after the explosion would not be simply carbonic acid and water, but would also contain carbonic oxide, and the process would then be attended with waste.

Mr. HOLROYD SMITH thought that question had really been answered already by Professor Kennedy's remark (page 529) that the governing occurred within certain limits of strength of charge. The control of the governor that regulated the proportion of gas to air in the mixture extended within a certain degree only; it did not go beyond the limit of explosiveness of the mixture. Explosion might be prevented by diluting the mixture until it became too thin to explode, so that the engine would then lose an impulse. But when using the double mode of controlling, care should be taken that the mixture was always such as would explode. If the control were carried beyond that limit, the engine would lose its impulse altogether, just as though the gas were shut off.

Mr. HEAD asked whether the relative proportion of air and gas was altered, and whether that alteration was attended with any inconvenience such as he had suggested. It was conceivable that the mixture might to a certain extent be explosive, and yet not completely explosive; and in the latter case, if there was too much gas in proportion to air, carbonic acid would not be formed, but only carbonic oxide, which meant waste.

Mr. Smith replied that the relative proportion of air and gas could be altered within a given range, so that the mixture should still be explosive. Within the explosive range the engine could be controlled by altering the mixture; but to go beyond that range was equivalent to shutting off the gas altogether.

The President enquired whether the speed was controlled by regulating the admission of the gas only or of the air only, or of both together. For the purpose of reducing the speed, was the gas killed with more air? And was the mixture perfectly explosive throughout the whole range of its alteration?

Mr. Smith replied that some engines were controlled only by the number of impulses per minute, the impulses themselves being always of the same strength. But under the dual control the speed could be regulated either by the number of impulses, that is by absolutely shutting off the gas; or by the strength of the mixture, that is by the force of the impulses. There was a certain range of strength, within which the explosive mixture was perfectly explosive; and in using the two methods of control the engine must be so adjusted that that range should not be exceeded.

Professor Kennedy said that within a wide range perfect combustion could be obtained with little or much gas to mix with the air, so as still always to get carbonic acid and not carbonic oxide when diminishing the proportion of gas within that range.

The President gathered that the control was effected by a reduction of gas for reducing the force of the impulse, and that the dilution of the explosive mixture must be effected always by an excess of air, in which case there would not be any waste of gas.

Professor H. S. Hele Shaw said that in University College, Liverpool, he had one of Mr. Shield's gas engines for driving certain machinery in the carpenters' workshop. It worked with the ignition tubes, which consisted of pieces of iron steam-pipe about $\frac{1}{4}$ inch

internal diameter, and about 14 inches long, welded over at the outer end. Ordinarily they lasted each for about a fortnight, and were replaced by a boy who did all the work of cleaning the engine. They used to cost twopence each, which meant a penny a week; the cost he believed was now somewhat reduced, and was at any rate insignificant. When the engine was kept running continuously all day, the tubes were replaced more frequently, and one week was then the practical limit of their duration. Although there was some clogging of the valve as the result of the explosions, yet that was a matter which required attention only once a week in properly cleaning the machine. The boy, whose wages were 4*s.* or 5*s.* a week, attended completely to the cleaning of the engine once a week; and there was never any trouble with that mode of ignition.

Mr. Arthur Paget, Vice-President, noticed that the incandescent tubes were said in the paper (page 511) to be destroyed in the course of a few hours, and 24 hours had been mentioned by Professor Kennedy (page 529) as their duration. He should therefore be glad to know what engine it was in which Mr. Shield had found them to last a fortnight (page 531), and what sort of tubes were used in that case.

Mr. Shield replied that the engine of which he had spoken was the Fawcett engine made by his firm. The igniting tubes were of wrought-iron, as described by Professor Shaw, and the time they lasted was one or two weeks; and, as explained by Professor Shaw, a boy receiving 4*s.* per week did all that was wanted. A friend of his, who had his house lighted by electricity, was using one of these engines for the purpose, which was looked after by his gardener; and he said that the duration of the tubes did not exceed a fortnight. This was really not anything very new as regarded the use of the tubes, and there was practically no difficulty with them. There had been some difficulty at first, because the tubes had not been placed at the proper angle; but as soon as they were adjusted at the proper angle, so that the ignition

at the hottest part of the tube was at the right spot, there had been no difficulty. The introduction of a dynamo or a battery, or any other means of getting an electric spark to explode the gas, he regarded as an unnecessary complication.

The President enquired what was the thickness of the tubes of $\frac{1}{4}$ inch diameter.

Professor Shaw replied that the tubes were made of ordinary steam-pipe, the internal diameter being not quite $\frac{1}{4}$ inch, and the thickness about 3-32nds of an inch.

M. Delamare said it was only after a number of trials that he had been led to adopt electricity for igniting the explosive mixture in the Simplex engine. Though not prepared to say that this was the best plan possible, he nevertheless regarded it as the simplest, and found that it allowed of readily starting the largest engines, and of using poor gas which was difficult to ignite by other means. In regard to economy also, having tried the Simplex engine with various other modes of ignition, he had found that the electric spark, applied by means of the movement of the slide-valve, was that which gave the best results.

The President asked whether it was a slide-valve or a mushroom valve that was used with the electrical ignition.

M. Delamare replied that it was a slide-valve, and it took the place of an interruptor such as was used in Lenoir's engine of 1860. The electric spark was produced in the cover of the slide-valve, and then the motion of the slide determined the moment of igniting the gas. A mushroom valve had the disadvantage of not always fitting equally close on its seat; and it occasionally happened that the flame leaked through it, and exploded the mixture too soon, before the crank had passed the centre. For this reason he had abandoned the mushroom valve in favour of the slide-valve for determining the instant of ignition.

(M. Delamare.)

Incandescent tubes, of which various speakers had given a favourable report, had been tried by himself some years ago, but unsuccessfully. No doubt others had applied them better, and by some improvement in detail had rendered them practically successful. At any rate he did not wish to attach too much importance to the trials he had made, because the main objection to the incandescent tubes was the difficulty there would have been in starting large engines with them; and the tubes could not be employed in such cases unless the starting were facilitated by some special arrangement. In this respect the Simplex engine which had been running at Messrs. Powell's works gave excellent results, being started with great ease. All that was necessary was to open the gas cock to the required extent, and then pass an electric spark for igniting the mixture. The explosion so produced gave the fly-wheel a sufficient impulse for starting the regular working of the engine. The battery used for producing the sparks was an ordinary cell containing bichromate of potash; the only difference was in the strength of the liquid used; and, as the result of a great number of experiments, such a strength had now been arrived at as would last for a month before wanting renewal. A large number of these Simplex engines had now been supplied both in France and abroad, and no trouble had been experienced on this score. In the details of the mechanism it had sometimes happened that all had not gone quite perfectly at the outset; but of the batteries he had never heard any complaints. Dynamos had also been tried with excellent results. They worked well, and caused the engine to work well also; but unfortunately it was not every attendant who could be trusted with them. And it had been found that small gas engines sent into the country with dynamos soon got out of order for want of proper care. The battery had therefore been preferred, wherever a choice had to be made between the two; and it was still found to give the least trouble.

The discharge of the burnt gases from the cylinder of the Simplex engine took place through a mushroom valve in the lower side of the cylinder at the back end, Fig. 21, Plate 107. There had never been the slightest trouble with these exhaust valves, and they were working as well at the present day as at the first starting of the engine.

To the excellent gas engines which had been mentioned as now in use in England he had not made special reference in the paper, because in the improvements introduced in the Simplex engine he had had in view rather the engines of Otto, Beau de Rochas, and Lenoir; and the paper would have extended to too great a length, had reference been made to the many other good engines now in use.

The plan of placing the dynamo quite close to the fly-wheel was not new; and his only reason for mentioning it was that he had found the best results were obtained by placing the dynamo in that position. This plan had been adopted after many months' trial, for the purpose of allowing a slight amount of slip at the moment of explosion, because he believed that the quivering of incandescent lights driven by a gas engine was occasioned at the moment of explosion. Previously a trial had been made of putting in an intermediate friction-pulley for driving the dynamo, so as to allow of a slight slip at the moment of explosion. That had answered pretty well, until it was at last found that the simpler plan of placing the dynamo quite close to the fly-wheel answered better. The slight slip which then occurred at the moment of explosion was perfectly effectual in preventing any quiver from being perceptible in the light; while at the same time it was also found that more lamps could then be driven per horse-power.

The President enquired whether any trials had been made in confirmation of the statement in page 522 of the paper, that, while at first sight it might be expected that delaying the point of ignition would entail a loss of power, yet experience showed that, though the area of the indicator diagram was diminished, the work measured by the friction brake was greater.

M. Delamare replied that the idea of igniting the explosive mixture a little later, instead of exactly on the dead point, had only lately occurred to him; and considerable economy had been found to result from simply delaying the explosion until the crank had got to 15° past the dead point, instead of exploding at the dead point; while the power of the engine was not diminished by that amount of

(M. Delamare.)
delay. In Fig. 34, Plate 112, was shown a specimen indicator diagram from an 8 horse-power Simplex engine, with cylinder 7·87 inches diameter and 15·75 inches stroke, running at 165 revolutions per minute.

The President asked what was the consequence of the compression being less at the moment of explosion, owing to the explosive mixture having somewhat expanded in the interval between the dead point and the point of explosion.

M. Delamare replied that the diminished compression was not attended with any loss of efficiency. In different sizes and makes of the Simplex engine the compression at the moment of explosion ranged from 70 up to 110 lbs. per square inch, with the same results always in favour of the later ignition. It must be borne in mind that delaying the explosion enabled the connecting-rod to assume an inclination sufficient for relieving the crank-shaft bearings from the greater part of the blow produced by the explosion, and for transferring it direct to the crank itself as useful force.

The President remarked that, as the compression was less at the moment of the later explosion, it looked as though the same result in economy might be realised, when igniting on the dead point, by not compressing to so great an extent as that which had previously been adopted with a view to enhancing the rapidity and efficiency of the explosion.

Mr. H. Coke Powell said the result would hardly be the same in that case, because the advantage of the delayed explosion arose from the fact that the piston was then already travelling at some speed in its forward stroke, and the connecting-rod was a little inclined at the moment of explosion; there was also much less loss by friction on the bearings. The over-compression had moreover the effect of reducing the weight of burnt and inert gases remaining in the cylinder to dilute the explosive mixture in the next stroke; for while the effective or driving length of stroke was shortened by not

commencing until the delayed point of ignition was reached, the expulsion of the burnt gases after explosion was continued to the very end of the return stroke; and the expelling stroke being thus longer than the driving stroke, their difference represented the reduction in the weight of burnt gases still remaining in the clearance space at the conclusion of the expelling stroke. The power absorbed in the over-compression was all given back in the driving stroke, and not only tended to bring the mass of the piston and other reciprocating parts more effectually to rest at the end of the compressing stroke, but also started this mass in the driving stroke before the explosion took place.

Mr. J. Macfarlane Gray thought it should be remembered that what was spoken of as a dead point was not really a dead point but a dead arc, of larger or smaller angle according to the coefficient of friction, the diameters of the crank-pin and shaft journals, and the ratio of crank to connecting-rod. Through the extent of the dead arc, no pressure whatever upon the piston would be capable of stirring the engine when standing still. But though no driving power could be produced through the dead arc, the friction through that arc could not be shirked; and this was the reason why the best plan was to let the crank pass clear beyond the dead arc, before the pressure was thrown upon it by the explosion.

The President was sure the Members would agree with him in according to M. Delamare and his partner Mr. Powell a hearty vote of thanks for the excellent paper that had been presented to the Institution upon a subject which was becoming daily of more and more interest and importance to engineers.

EXCURSIONS.*

The Visits and Excursions in connection with the Paris Meeting were for the most part organised by the kindness of the Reception Committee of the Société des Ingénieurs Civils de France.

On TUESDAY AFTERNOON, 2nd July, a visit was paid to the Paris Exhibition, the Members assembling at the Salle de Travail of the Société des Ingénieurs Civils, for making their tour of inspection in groups devoted to mines, metallurgy, machinery, boilers and sugar machinery, railways, electricity, and public works; the several groups were conducted by Members of the Société.

In the evening a Reception was held at the House of the Société des Ingénieurs Civils, 10 Cité Rougemont, by the President, M. Eiffel, and the Reception Committee and other Members of the Société.

On WEDNESDAY AFTERNOON, 3rd July, the Members visited the Museum of the Conservatoire des Arts et Métiers, to inspect especially two celebrated musical automatons, which were exhibited in action. They afterwards visited the Paris Lyons and Mediterranean Railway Locomotive Works, 1 Rue du Charolais, Avenue Daumesnil, under the guidance of M. Henry, Locomotive and Carriage Superintendent, M. Baudry, his assistant, and MM. Léon, Chabal, Maréchal, Vanderheym, and Hovine, departmental engineers; the Gas Engine Works of Messrs. Rouart Frères et Cie., 137 Boulevard Voltaire; and the Electric Lighting and other arrangements of the Grand Opera House, under the guidance of M. Vernes. Descriptions of these Works are given in pages 549–552 and 569. Conveyances to most of the Works visited on Wednesday, Thursday, and Friday afternoons were provided by the kindness of the Société des Ingénieurs Civils.

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* The notices appended of the various Works &c. visited in connection with the meeting were kindly supplied for the information of the Members by the respective proprietors or authorities; several of them have been abridged from descriptions which appeared in *Engineering* and other journals about the time of the meeting.

On Wednesday evening the Institution Dinner was held at the Hôtel Continental, 3 Rue Castiglione, Paris, and was largely attended by the Members and their friends. The President occupied the chair, and the following Guests were amongst those invited, some of whom however were unavoidably prevented from being present.

The Right Honourable the Earl of Lytton, G.C.B., *British Ambassador Extraordinary and Minister Plenipotentiary.* M. Tirard, *Minister of Commerce and Industry*; M. Yves Guyot, *Minister of Public Works*; and M. Faye, *Minister of Agriculture.* MM. Sébillot and Dautresme, *Chefs de Cabinet.* M. Picard, *President of the Railway Consulting Committee*; M. Nicolas, *Directeur du Commerce Intérieur.*

Reception Committee of the Société des Ingénieurs Civils.—M. Gustave Eiffel, *President.* MM. Victor Contamin, Ernest Polonceau, Sylvain Périssé, and Paul Jousselin, *Vice-Presidents.* M. Henry Couriot, *Treasurer.* MM. Henri Vallot, Eugène Bertrand de Fontviolant, Georges Cerbelaud, and Henri Émile Bert, *Secretaries.* MM. Achille Brüll, Alexandre Gottschalk, Samson Jordan, and Émile Trélat, *Past-Presidents.* MM. Gustave Canet, Anatole Mallet, Jules Morandière, and Paul Regnard, *Members of Council.* MM. David Banderali, François Fernand Bourdil, Eugène Hippolyte Boyer, Oscar Gabriel Buron, Charles Casalonga, Camille de Cordemoy, Paul Decauville, Maurice Demoulin, Raoul Doux, Charles Delapoix de Fréminville, Jean Baptiste Gobert, Ernest Mayer, Edgar Monjean, Adolphe Salles, Henri Vaslin, Amédée Vernes, and Georges Whaley, *Members.* M. Armand de Dax, *Agent-General.*

Other Members of the Société des Ingénieurs Civils.—MM. Charles de Comberousse, Joseph Farcot, Hildevert Hersent, Alexandre Lavalley, George Love, Louis Martin, Henry Mathieu, Léon Molinos, Émile Muller, and Francisque Reymond, *Past-Presidents.* M. Gustave Loustau, *Honorary Treasurer.* MM. Alfred Hallopeau, Paul Buquet, Charles Herscher, Léon Appert, Jules Carimantrand, Édouard Lippmann, Louis Rey, Jules Charton, Louis Berthon, Léon Vigreux, Auguste Moreau, Max de Nansouty, Louis Parent, Alexandre Gouilly, Louis Boudenoot, and Hubert Desgrange, *Members of Council.*

Conservatoire National des Arts et Métiers.—Colonel Laussedat, *Director*; M. Léon Masson, *Engineer.*

Mr. Henry Chapman, *Honorary Local Secretary for the Paris Meeting.* M. A. Ansaloni, M. Édouard Delamare-Deboutteville, Mr. Job Duerden, Mr. J. Macfarlane Gray, Mr. Thomas Urquhart, *Authors of Papers.*

Paris Exhibition.—Sir Polydore de Keyser, *President of the British Committee*; Mr. H. Trueman Wood, *Commissioner of the British Section*; Mr. J. Aylmer, *Honorary Secretary*; Mr. J. H. Cundall, *Engineer*; Mr. J. Schultz, *Assistant Engineer.* M. Alphand, *Director-General of Works*; M. Georges Berger, *Director-General of Management*; M. Grison, *Director-General, Finance Department*; M. Bechmann, *Engineer, Water Supply*; M. A. de Lacretelle, *Secretary, Foreign Sections*; M. Halphen, *Secretary to Machinery Committee*; M. Bourdon, *Engineer to Mechanical Department*; Mr. Gunnell, *Engineer of the United States Section*, and Mr. Pickering, *Superintendent*; M. Carez, *Engineer of the Belgian Section*; M. Grille, *General Manager of the Exhibition Railways*; M. Colin, *Engineer of Class* 61 (*Railway Material*); Mr. T. Campbell Clarke, *British Juror, Class* 13 (*Musical Instruments*); Mr. Conrad Cooke, *British Juror, Class* 15 (*Scientific Instruments*); Mr. H. T. Ellicott, *British Juror, Class* 41 (*Products of Mines, and Metallurgy*); Mr. W. H. Preece, *Electrician to General Post Office, and British Juror, Class* 62 (*Electricity*); and Professor Francis Elgar, *Director of Dockyards, and British Juror, Class* 65 (*Navigation and Life-Saving Apparatus*).

M. Henry, *Locomotive and Carriage Superintendent, Paris Lyons and Mediterranean Railway*; M. Baudry, *Assistant*; and M. Maréchal, *Works Manager.* M. Marin, *General Manager of the Western Railway of France*; M. Foulon, *Secretary*; M. Clerc, *Director of Works*; M. Morlière, *Engineer-in-Chief*; M. Bouissou, *Permanent-Way Engineer*; M. Clérault, *Locomotive and Carriage Superintendent*; and M. Vétillard, *Superintendent of Central District.* M. Mathias, *Locomotive and Carriage Superintendent, Northern Railway of France*; M. Sartiaux, *Assistant Engineer*; and M. Sauvage, *Works Manager.* M. Salomon, *Locomotive and Carriage Superintendent, Eastern Railway of France*;

M. Flaman, *Chief Inspecting Engineer*; and M. Birckel, *Engineer*. M. Solacroup, *Assistant Locomotive and Carriage Superintendent, Orleans Railway*. M. Chabrier, *Managing Director, Transatlantic Steam Navigation Co. of France*.

M. Vétillart, *Engineer, Calais Harbour Works*; M. Rau, *Manager of the Continental Edison Co.*; MM. Henri and Alexis Rouart; Baron Deslandes, *Chairman of the Paris Compressed-Air Co.*, M. Popp, *Manager*, and M. Martin, *Engineer*; M. Gaget-Gauthier; MM. Plassard, Morin, and Fillot, *Proprietors of the Magasins du Bon Marché*, M. Karcher, *Secretary*, and M. Lelong, *Engineer*; MM. Louis Sautter and Paul Lemonnier; M. Victor Veysy; MM. Émile and Pierre Decauville.

M. Haton de la Goupillière, *Inspecteur Général des Mines, Directeur de l'École supérieure des Mines*; M. Carnot, *Ingénieur-en-Chef des Mines, Inspecteur de l'École supérieure des Mines*; General Henry, *Directeur de l'École Polytechnique*; M. Lagrange, *Directeur de l'École Nationale des Ponts et Chaussées*; M. Cauvet, *Directeur de l'École Centrale*; M. Fontaine, *Président de la Société des Anciens Élèves des Écoles Nationales d'Arts et Métiers*; M. Liébaut, *Président de la Chambre syndicale des Ingénieurs-Constructeurs-Mécaniciens*; M. Berrier-Fontaine, *Sous-Directeur de l'Arsenal de Toulon*; Commandant Deport, *Directeur de l'Arsenal de Puteaux*.

M. Henri Schneider, *Creusot Works*; M. Arson, *Engineer, Paris Gas Co.*; M. Cornuault, *Manager of the Marseilles Gas Co.*; M. d'Eichthal, *Managing Director, Railway Rolling Stock Co.*; M. Duval, *General Manager, Fives-Lille Co.*, and M. Lantrac, *Engineer*; Colonel de Bange, *General Manager of the Anciens Établissements Cail*, and M. Bougault, *Assistant Manager*; M. Jouet Pastré, *Managing Director of the Chantiers de la Mediterranée*; M. Le Belin de Dionne, *General Manager of the Chantiers de la Gironde*; M. de Cabrol, and M. Thiébaut, *Managing Directors of the Chantiers de la Loire*.

Mr. Henry R. Towne, *President of the American Society of Mechanical Engineers*, and Mr. William Kent, *Vice-President* Professor R. H. Thurston, *Cornell University, U.S.*; M. Habets, *Secretary of the Société des Ingénieurs sortis de l'École de Liége* M. Flamme; M. Schaar; M. Théry; Captain de Labouret; Mr.

George M. Bond; Mr. Benning; M. Duval fils; Mr. Charles Richards; Mr. Bowes; Mr. Gody; and Mr. Beatty Kingston.

The President was supported by the following Officers of the Institution;—Mr. Jeremiah Head, *Past-President*; Mr. Daniel Adamson, Sir James N. Douglass, Mr. Arthur Paget, and Mr. Joseph Tomlinson, *Vice-Presidents*; Mr. Benjamin A. Dobson, Professor Alexander B. W. Kennedy, and Mr. E. Windsor Richards, *Members of Council.*

The usual loyal toasts for both countries having been duly honoured, the President proposed the "Société des Ingénieurs Civils," which was acknowledged by their President, M. Gustave Eiffel. Mr. Jeremiah Head proposed "The Directors and Managers of the various Establishments where the Members are being received during their Meeting in Paris," which was acknowledged by M. Decauville. The toast of "Our Guests," proposed by Mr. Daniel Adamson, was acknowledged by Professor R. H. Thurston, who also proposed the final toast of "The Institution of Mechanical Engineers," which was acknowledged by the President.

On THURSDAY AFTERNOON visits were made to the following Works, descriptions of which are given in pages 552–560 and 565–6.

M. Popp's Compressed-Air Power Supply Station, 8 to 16 Rue St. Fargeau.
Eden Theatre, Compressed-Air Machinery.
M. Boudenoot's Vacuum Power Supply Station, 41 Rue Beaubourg.
Sewers: Place du Châtelet and Place de la Madeleine.
Messrs. Sautter Lemonnier and Co.'s Electric-Light Works, 26 Avenue de Suffren.

Conveyances to the Compressed-Air Works were kindly supplied by M. Popp; and on returning thence the Members were taken to the Eden Theatre, to see the application of compressed air to the machinery there in use.

The Sewers were entered at the Place du Châtelet, under the guidance of M. Bechmann, Ingénieur-en-Chef des Ponts et Chaussées, and at the Place de la Madeleine, under the guidance of an assistant engineer. The passage was made partly in boats and partly in cars, both being propelled by means of large shutters or vanes, which are

let down into the water and acted upon by the current (see Proceedings 1878, page 548).

The visit to Messrs. Sautter Lemonnier and Co.'s Works was made in the evening, when the electric-lighting arrangements could be inspected to greater advantage. Some high-speed vertical single-acting engines were shown at work, and the Members were afterwards taken to the top of the tower in the works to see the action of two powerful electric-light projectors, similar to those on the top of the Eiffel Tower.

On FRIDAY, 5th July, the Members assembled at the foot of the Eiffel Tower at eight o'clock a.m., where they were received by M. Eiffel, President of the Société des Ingénieurs Civils and Chairman of the Reception Committee, and by a large number of the Members of the Société, under whose guidance and invitation they were conducted first to the top platform of the tower, at 906 feet height above the ground, whence many ascended to the lantern gallery some 65 feet above. A description of the tower is given in pages 561–565; and of the lifts in M. Ansaloni's paper (pages 350–364), and in M. Eiffel's supplementary remarks respecting their working up to date (pages 365–9 and 376–8). At eleven o'clock the Members were entertained at luncheon by the Société des Ingénieurs Civils, on the first platform of the tower, at a height of 189 feet above the ground.

In the afternoon alternative visits were arranged to the following Works, descriptions of which are given in pages 566–573.

Bon Marché Electric Lighting and Repairing Shops, corner of Rue de Sèvres and Rue du Bac.
Edison's Electric Installation in the second courtyard of the Palais Royal.
Western Railway (Hydraulic Machinery &c.), Cour de Rome, St. Lazare Station.
MM. Perreur-Lloyd père et fils (Primary Batteries), 118 Rue de Vaugirard.

The visit to the Bon Marché was made under the guidance of M. Plassard, one of the proprietors, and of M. L. Lelong, head of the machinery department. Ladies were admitted to inspect the

arrangements for the comfort of the employés. M. Rau, Manager of the Continental Edison Co., took charge of the party who visited the Edison installation at the Palais Royal. At St. Lazare Station the Members were welcomed in the grand hall of the hotel by M. Honoré, Engineer of the Magasins du Louvre; after which the inspection of the Works was made under the guidance of M. Morlière, Engineer-in-Chief, and M. Bouissou, Permanent-Way Engineer. By the kindness of M. Victor Veysy conveyances from the Exhibition were provided for the Members visiting MM. Perreur-Lloyd's Works, over which they were conducted by M. Marcel Perreur-Lloyd.

In the evening the Members visited the Exhibition to see the electric lighting and the illumination of the fountains.

On SATURDAY, 6th July, two alternative Excursions were made.

On the invitation of M. Decauville, a large number of Members, under the conduct of M. Polonceau, Vice-President of the Société des Ingénieurs Civils, were conveyed from the Lyons Station in Paris by special free train, by the kindness of the Paris Lyons and Mediterranean Railway, to Corbeil, about 21 miles south from Paris, being accompanied by M. Picard, General Manager of the line. Thence in a train of Decauville cars they proceeded to Petit-Bourg to visit the Decauville Portable-Railway and Rolling-Stock Works, a description of which is given in pages 573–576. Over these they were conducted by M. Decauville and his brothers, MM. Émile and Pierre Decauville, his partners and joint managers. The facility with which the portable railway could be laid and relaid was practically demonstrated in the experimental grounds attached to the works; and the stiffness and good quality of the material employed was shown by bridging a ditch 7 feet wide with the rails alone of 14 lbs. per yard, and running over them a wagon carrying a gun weighing $3\frac{1}{2}$ tons. The capabilities of these narrow-gauge railways for dealing with heavy loads was further illustrated by manœuvring a model of a 48-ton gun mounted on a pair of double-bogie wagons with swivel frames. By the efforts

of only a dozen men the gun was readily transferred from one line to another at right angles, and was reversed end for end, by employing only the ordinary small turntable at the point of junction. From the Works the Members were conveyed by special tramway to M. Decauville's residence, the Château des Tourelles, where they were entertained by him at luncheon. The return journey to Paris in the afternoon was made by means of the same train arrangements as in the morning.

The Members returning to England on Saturday visited at Calais the New Harbour Works (pages 576–581) under the guidance of M. Vétillart, Ingénieur-en-Chef du Service Maritime. Before leaving they were entertained at luncheon by the Calais Chamber of Commerce. A handsome bronze medal, struck to commemorate the inauguration of the works in the previous month by M. Carnot, the President of the French Republic, was presented to the President of the Institution by M. Fournier, President of the Chamber of Commerce.

PARIS LYONS AND MEDITERRANEAN RAILWAY LOCOMOTIVE WORKS.

The Locomotive Works in the Rue du Charolais, near the Lyons Railway Station, Paris, are occupied with the building and repairing of engines and tenders and the repairing of carriages, about 700 hands being employed for the former and 400 for the latter. They are capable of turning out about 40 locomotives per annum, besides executing the heavy repairs of about 100 engines. There are two other locomotive works belonging to the railway, one at Oullins near Lyons, employing 1,100 hands, and the other at Arles employing 500. At Oullins there are also carriage works larger than those in Paris. The principal wagon-repairing shops are at Villeneuve-St.-Georges near Paris, at Dijon, at Lyons, at Courbessac near Nîmes, and at Marseilles.

At the Paris works there are two erecting shops, containing eighteen and twenty-two engine-pits respectively, each of which is provided with a small overhead travelling crane worked by hand, and capable of lifting up to two tons. In neither shop is there any general overhead travelling crane, but each shop is served by a traversing table which passes down its centre, being worked by steam in one shop and in the other by hand; whilst for lifting the engines when removing or replacing wheels there is provided a twenty-ton crane with a kind of gantry framing, which by means of the traversing table can be brought over any pit. This large crane runs on rails laid to a gauge wide enough to keep the side legs well clear of the engine which is being lifted; and rails are laid to this wide gauge for each pit, in addition to the ordinary rails on which the engines stand.

In the fitting and machine shop, which adjoins the erecting shop, is a large machine for shaping and drilling locomotive frame-plates. It has a heavy table, whereon can be fixed a pile of frame-plates, over which travel four heads, two for both drilling and slotting, and the other two for drilling only. Adjoining is another fitting and machine shop, in which a number of milling tools are at work, including a heavy milling machine on the copying principle. In this shop also is a double horizontal boring machine, having the two boring bars fixed at an invariable distance apart, for boring simultaneously the two inside cylinders for a locomotive, which are generally cast together in one piece having the upper surface hollow, like an inverted saddle, with facing strips to receive the boiler barrel.

In the boiler shop and smiths' shop, both of which adjoin the machine shops, the appliances include a hydraulic riveting machine; a furnace, of which the roof can be run back on rails, for annealing the boiler plates after punching and bending; and steam-hammers and cranes, for which the steam is supplied by Field boilers heated by the waste gases from the furnaces.

The testing shop, which is fitted up with great completeness, contains two vertical testing machines capable of applying strains of 25 tons and 100 tons respectively; a cable-testing machine capable

of exerting a pull of 100 tons on chains nearly 100 feet long; a testing machine placed in a pit beneath the floor level, for applying transverse and compression strains to tires and axles; a machine for testing india-rubber buffer-springs; and another for testing belts. For testing the locomotives under steam, a rectangular pyramidal frame has been put up, from which they are slung by their buffer beams, or by adjustable slings passing under their leading and trailing ends; they are then run round at different speeds, clear of the rails. The engine draws its own diagram of its vertical and horizontal oscillations; and instruments have been devised for measuring the stresses produced when the engine is held from moving. The object is to obtain such an indication of the stresses and oscillations produced in actual running as to afford a basis for modification in design; but the experiments have not yet been carried to such an extent as to admit of definite conclusions being arrived at. Most of the railways running out of Paris have sent their engines to be thus tested at these works.

GAS-ENGINE WORKS.

At the works of Messrs. Rouart Frères et Cie., 137 Boulevard Voltaire, are manufactured Bisschop and Lenoir gas engines, the former up to 1 horse-power, and the latter from 1 to 24 horse-power; Lenoir petroleum engines from 2 to 12 horse-power; Gramme machines for electric lighting and for electro-metallurgical purposes; refrigerating and ice-making machines; disintegrating and crushing machinery; centrifugal pumps, steam-pressure regulators, lucigens, &c. The refrigerating machines, whether for domestic or commercial use, are worked by the employment of an ammoniacal solution heated in a closed vessel. For cooling brewers' cellars, chloride of calcium, refrigerated to a very low temperature by apparatus of this kind, is allowed to trickle down vertical sheets of wire-gauze; and the plan has been in use at the Morgue from 1880 without interruption. The disintegrating and crushing machines consist of a pair of flat circular discs, each of which has one of its faces

studded with a number of teeth. These are placed face to face, close to each other, one of the discs being fixed, whilst the other is caused to rotate at from 700 to 800 revolutions per minute.

COMPRESSED-AIR POWER SUPPLY.

The works of the Compagnie Parisienne de l'Air Comprimé, started in 1881 by M. Victor Popp and situated in Rue St. Fargeau, are now transmitting through some forty miles of mains compressed air at a pressure of 90 lbs. per square inch, which is utilised to the extent of nearly 3,000 horse-power.

The special object in the first instance was to establish and maintain a system of pneumatic clocks in the streets; and for this purpose mains have been laid over a considerable portion of Paris. The means employed for working the large number of clocks now in use are very simple; they comprise a central station, the necessary mains and service pipes, and the clock dials with the special mechanism employed. At the central station a clock giving standard time actuates at intervals of a minute a valve connected with the reservoir of compressed air; during the first twenty seconds of each minute the valve allows the air to pass from the reservoir into the mains, and during the succeeding twenty seconds it permits the air to escape from the mains into the atmosphere. The mains consist of circuits of pipes laid from the central station, and connected together at frequent intervals, in order to multiply the means of supplying any given point. The pipes are of iron or lead, varying in diameter from 1·06 to 0·39 inch, and are fitted at short intervals with three-way valves, accessible from the street surface, in order to divide the system into small sections without interfering with the service; the small service pipes leading from the mains into the houses are of lead, and vary from 0·39 to 0·16 inch diameter. The special device attached to each clock consists of a small air-receiver or bellows, which by its successive dilatations and contractions imparts a regular movement to a small connecting-rod carrying at one end a paul that works into a wheel cut with sixty teeth and fixed to the minute hand;

a second paul prevents the backward movement of the wheel. The hour hand is driven by a train of ordinary gearing. Some of these clocks are fitted with a bell for striking the hours, the mechanism being wound up gradually by each stroke of the bellows. The controlling clock at each station thus acts as the heart of the system of which the station is the centre, opening and closing at regular intervals the valve whereby air impulses are transmitted through the pipes to the various points of service. At the St. Fargeau works are two horizontal steam engines of Corliss type, made by Messrs. Farcot of St. Ouen, each of 60 horse-power, either of which is capable of supplying the compressed air necessary for working the pneumatic clocks in Paris, while the other stands in reserve. The actual power at present required for this purpose at the works is 35 horse-power, which is distributed through 40 miles of mains to 4,000 houses in the first and second arrondissements of Paris, and works about 9,000 clocks.

As soon as it was found that the power produced was in excess of that required for working the clocks, the distribution of compressed air was commenced upon a much larger scale, for the transmission of power to various parts of Paris, and for a great variety of purposes, ranging from the working of sewing machines to the driving of printing machinery, electric-light apparatus, elevators, and other appliances. The extension of the works was begun in 1886, and the building now containing the engines and compressors is a rectangular structure open from end to end, 328 feet long and 66 feet wide; adjoining but separate from the engine-room is the boiler-house, 66 feet long and 36 feet wide. The structure is entirely of iron, the spaces between the standards being filled in with brickwork. The first engine erected was a beam engine of 350 horse-power, built by Messrs. Casse and Co. of Lille; and the works, as completed in 1887, contain also a range of six horizontal compound engines by Messrs. Davey Paxman and Co. The cylinders of each compound engine are 22 and 35 inches diameter and 4 feet stroke; each engine, when working at 50 revolutions per minute and at the effective steam pressure of 85 lbs. per square inch, is capable of developing 400 horse-power,

making a total of no less than 2,400 horse-power. The air-compressing cylinders, one to each steam cylinder, are 23·62 inches diameter, and are placed on the same bed-plates and driven from the piston-rods of the engines. For cooling the compressed air a jet of water is admitted at each end of the compressing cylinder, and the latter is drained by a tap at each end. The compressed air is delivered from the compressors through spring-loaded valves into seven cylindrical receivers, $6\frac{1}{2}$ feet diameter and 41 feet long, placed end to end, and connected together by pipes with valves and by-passes in such a way that any one receiver can be isolated for repairs or other purposes. The connecting pipes are 12 inches diameter, and are so arranged that, if it is found desirable, the compressors can deliver the air direct into the mains.

The boiler-house contains seventeen boilers, $14\frac{1}{2}$ feet long and $7\frac{1}{2}$ feet diameter, having two flues $2\frac{1}{2}$ feet diameter with diagonal circulating tubes; each boiler has about 1,100 square feet of heating surface, giving a total of over 18,000 square feet. When the works are in full swing, about 50 tons of coal are consumed per day, representing an annual consumption of nearly 20,000 tons. The cost of water is sufficiently high in Paris to render it desirable that as much economy as possible should be effected in its use. The condensing water from the engines is accordingly collected and pumped up to the top of a large rectangular structure, which is provided with seven stages, having a total surface of about 32,000 square feet; in flowing over this large surface the water is cooled on its way to the reservoir upon the top of which this cooler is placed, whence it is brought back to the engines to be used over again; so that only the water required to make up the loss due to evaporation has to be supplied from the city mains.

Five new engines and compressors, with ten new boilers to supply them, are in course of construction by the Société Cockerill. In addition to repairing shops on a small scale, and offices, there is also a laboratory, used chiefly for testing the meters supplied to each consumer, by means of which the charges are determined. The mode of testing the meters is by comparing their readings with those of a large standard gas meter, the air pressure being previously

reduced to a convenient extent. The remainder of the space in the works is utilised for coal stores, a very large stock being always kept on hand to provide against the contingency of the supply being interrupted. The works are lighted by electricity, generated by Thomson-Houston dynamos.

A subway leading from the works gives access to the great system of underground tunnels by which Paris is traversed, and in which as far as possible the mains are laid. The pipes are of cast iron, about 12 inches inside diameter, and the two lines of mains are each laid in duplicate. As in the case of the pipes for working the pneumatic clocks, the two lines of mains are connected at short intervals by cross-pipes, 12 inches diameter, so as to divide up the system into as many distinct sections as possible, and thereby to render the supply as free from the dangers of interruption as is possible. The branch or service pipes from the mains into the premises of the consumers vary from $1\frac{1}{2}$ to 4 inches diameter. In order to prevent interruption of the service during repairs or addition of new branches, a large number of valves are placed upon the mains, so as to isolate any particular lengths and to turn the flow of compressed air into special directions. Although before leaving the works the water contained in the air is removed in a separating reservoir, a certain quantity passes into the mains; and unless means were taken to remove it, considerable trouble might result, especially in the smaller service pipes. Accordingly at intervals, and especially at the lowest parts of the lines, automatic separating syphons are introduced, which appear to be practically efficient. Before being conducted to a motor or distributed throughout a building by branch pipes, the compressed air flows into a pressure regulator, which reduces the pressure to a certain extent and maintains it uniform, so that none of the slight variations in the mains may be transmitted to the motors. From the regulator the air flows through the meter which records the amount consumed; and after passing through a heating chamber it is delivered direct to the motor. Engines of special design are employed for converting the power of the compressed air into useful work; they vary from motors adapted for driving a sewing machine

up to engines of 100 horse-power. The air is supplied at a mean pressure of from 45 to 70 lbs. per square inch, and at the rate of 1·5 centime per cubic mètre reduced to atmospheric pressure. The purposes for which the compressed air is used may be divided into three distinct classes, as follows:—first, during the day, for the distribution of motive power, and for ventilation and cooling &c.; second, at night, for the production of electricity for lighting; third, continuously during the twenty-four hours, for driving the pneumatic clocks. The first service lasts for about ten hours, from eight in the morning till six in the evening; the second from six in the evening till two in the morning in summer, and in winter from four in the afternoon till five in the morning, and in some establishments until daylight. Thus, although the conditions of supply change considerably during each day, and the demand upon the central station, except for the pneumatic clocks, is very variable, the work of the condensers and air-compressors is continuous, and the variations and requirements are sufficiently regular for determining within comparatively narrow limits the quantity of reserve power it is necessary to provide.

The principal uses for which the compressed-air supply has already been employed, besides driving the pneumatic clocks, include driving pneumatic motors for actuating all kinds of machinery, winding up the printing telegraph instruments in the Paris post-offices, shifting wine from one cask to another, raising water from the basement to the top of a house, ringing pneumatic bells, blowing whistles, emptying cesspools, ventilating and cooling rooms, working lifts, shearing metals, cutting stuffs, &c. Additional engines and air-compressors are in course of construction for a further extension of the works.

COMPRESSED-AIR MACHINERY AT THE EDEN THEATRE.

At this theatre, situated near the Grand Opera House, a very complete set of compressed-air machinery has been fitted up for electric lighting and many other purposes, and is worked by the

Compressed-Air Power Supply. Not only does the compressed air drive the dynamos which supply the current for lighting the building and for producing optical effects on the stage, but it also supplies the power for many remarkable mechanical stage-effects.

VACUUM POWER SUPPLY.

The supply of power by vacuum, as carried out in Paris by MM. Petit and Boudenoot, consists in maintaining, by means of exhausting engines working at the central station at 41 Rue Beaubourg, a reduced pressure in the mains to the amount of as nearly as possible two-thirds of a perfect vacuum. Service pipes from the mains pass into the premises of the users, and are connected with the motors; and work is thus performed by the difference in pressure between the atmosphere and the vacuum in the mains. The exhausting engines do not exhaust direct from the mains, but from a reservoir serving to some extent as a regulator, from which the mains are laid either under the streets or in the subways; and the motors are started or stopped by simply opening or closing a valve on the service pipe. The engines at the central station were constructed by M. Brasseur of Lille; and the motors were designed and made by MM. Sarallier and Pradel of Paris.

There are three exhausting engines of about 90 horse-power each; one of them is independent, while the other two can be coupled together. The steam cylinder is $13\frac{3}{4}$ inches diameter and 42 inches stroke, and works with a boiler pressure of 85 lbs. per square inch. The exhausting cylinder of 41 inches diameter is in the same line with the steam cylinder, both pistons being on the same rod. Pressure regulators, indicators, and counters, record continuously the vacuum in the mains, and the revolutions made by the engines, whereby a check is obtained upon the amount of power supplied.

The motors driven by the vacuum are made in three sizes, of $\frac{1}{2}$ horse-power, 1 horse-power, and $1\frac{1}{2}$ horse-power; the last seems to be the maximum that can be worked with advantage, and where more power is required it is obtained by coupling two motors together. Each motor comprises four principal parts: the base, the

cylinder, the piston, and the cylinder cover on which are cast brackets that carry the crank-shaft. The base is divided into two chambers, one of which is in communication with the exhausted mains, whilst the other is open to the atmosphere. The distribution is controlled in the ordinary manner by a slide-valve worked by an eccentric. An ordinary centrifugal governor acts on a piston-valve, which controls the quantity of atmospheric air admitted to the valve-chest.

In order to secure for the motors furthest from the central station the full amount of power intended, it is necessary that a uniform vacuum should be maintained at the ends of the mains; and for this purpose it is requisite to increase the vacuum at the station in order to compensate for the losses resulting from the demands of the intervening motors; and the exhausting engines have accordingly to be driven at a higher speed. It has been ascertained by means of experiment what degrees of vacuum are necessary at the station in order that, at the end of the circuit, the motors shall work properly at all hours of the day, no matter what variation in load may be thrown upon them at different hours; these variations are tolerably uniform from day to day, and are classified as maximum, great, average, small, and minimum. A sector graduated in accordance with this classification carries a needle, which is adjusted in the position corresponding at the moment with the demand upon the exhausting engines. Another needle with two arms is actuated by an ordinary vacuum gauge; as long as the vacuum is being maintained properly, the adjustable needle occupies a position between these two arms. But as the work done by the motors increases or diminishes to a marked degree, one or other of the arms of the needle actuated by the vacuum gauge comes into contact with the adjustable needle, and the contact establishes electrical communication with a bell, the ringing of which warns the attendant that the speed of the exhausting engine must be altered. The present length of the exhaust mains from the central station is about a thousand yards. In addition to the exhausting engines there is also at the station a small electric-light installation, comprising a horizontal Corliss engine of 110 horse-power, which drives two Gramme dynamos of 370 ampères and 110 volts, and is supplying

current regularly to 500 lamps; it is expected that before long 800 lamps will be so supplied.

THE SEWERS OF PARIS.

Sewage properly so called is not as yet delivered into the sewers of Paris, but is discharged into cesspools, whence it is periodically removed and dealt with separately. The liquid overflowing from some of these cesspools, and the greater portion of the ordinary rainfall, and all the domestic and commercial waste water of the city, are discharged into the street sewers, and by these are conducted into the large main or collecting sewers. The three main or collecting sewers are constructed along the lower levels of the city, and receive the natural drainage as well as the contents of the street sewers. The first is on the right bank of the Seine, and is known as the departmental collector; it commences at the point of intersection between the Rue Oberkampf and the Rue Ménilmontant and passes under the old outside boulevards. Its course is broken by three bends, by which it crosses the basin of La Villette, the fortifications, and the Grande Route St. Denis; and it falls into the Seine near the Île St. Ouen. The sewage dealt with by this collector is of the worst kind, containing as it does the impurities from the slaughter-houses and gas-works, the factories of La Villette, Montmartre, &c., and even the overflow from the Bondy depôt. The second collector, also on the right bank of the river, commences at the Arsenal basin, follows the quays, and runs under the Rue Royale, the Boulevard and Rue Malesherbes, and the Route d'Asnières; and falls into the Seine above the railway bridge. At the Place du Châtelet it is enlarged to receive the contents of the collector of the Boulevard Sébastopol; at the Place de la Concorde it is joined by the sewer of the Rue de Rivoli; at the Place de la Madeleine it absorbs the sewer of the Petits-Champs; and at the junction of the Boulevard Malesherbes and the Rue de la Pépinière it receives a sewer following the course of the brook of Ménilmontant. The third collector is the only one on the left bank of the Seine; at its commencement it absorbs the

river Bièvre which at one time used to flow into the Seine above the Pont d'Austerlitz; it then runs behind the Jardin des Plantes, towards the Boulevard St. Michel, and passes along the quays as far as the Pont d'Alma; here it crosses under the river through a double syphon, and passing under the height of Chaillot and the Avenue Wagram, crosses the village of Levallois-Perret, and joins the second collector on the right bank, about 550 yards above the point of discharge. Near the Pont d'Alma on the left bank, it receives the Mont Parnasse and Grenelle sewers; and on the right bank the Auteuil collector falls into it.

The second of the three main or collecting sewers is the one usually shown to visitors, who are conveyed through it in boats, propelled by large shutters or vanes which are let down into the water and carried forwards by the current. The sewage water flows along a central channel, about $11\frac{1}{2}$ feet wide and 7 feet deep, along each side of which runs a paved path about 3 feet wide; and the arch overhead rises to about $9\frac{3}{4}$ feet above the side paths, the whole height of the sewer from the bottom of the channel to the crown of the arch being about $16\frac{3}{4}$ feet. Visitors are also conveyed through the sewers of the Rue de Rivoli and of the Boulevard de Sébastopol in wagons, which are likewise propelled by vanes let down into the current. In these sewers the central channel is 4 feet wide, and along each side path is laid a rail, the pair forming the track whereon run the wagons, bridging over the central channel along which the water flows. The sewers are lighted throughout with oil and electric lamps, and are well ventilated naturally, so that there is no unpleasantness in going through them. For removing any obstruction in the channel, the vane or shutter on the wagon or boat, which is just smaller than the section of the channel, is lowered into the water, thereby causing a head of from 6 inches to 12 inches to accumulate behind it, sufficient for removing the obstruction. A similar method is used to cleanse the syphon under the river at the Pont d'Alma, by means of a ball of firwood, about $2\frac{3}{4}$ feet diameter or 6 inches less than the bore of the syphon, through which it is carried by the pressure of the water behind it. About 700 men are employed constantly in cleansing the sewers.

THE EIFFEL TOWER.

The Eiffel Tower, Plate 61, consists essentially of an iron pyramid composed of four great curved columns, independent of each other, and connected together only by belts of girders at the different stories, until the columns unite at the top of the tower, where they are connected by ordinary bracing. The leading principle followed in the design was that adopted by M. Eiffel in all his lofty structures, namely to give the corners of the tower such a curve that it should be capable of resisting the transverse effects of wind pressure without necessitating the connection of the members forming the corners by diagonal bracing.

The actual work of the foundations was commenced in January 1887; but a great number of borings had previously been made on the Champ de Mars, which revealed the existence of a bed of hard compact clay 52 feet thick, resting on a chalk substratum, and capable of carrying with safety a load of from three to four tons per square foot. The bed of clay dips slightly from the École Militaire towards the Seine, and underlies a deposit of compact sand and gravel, which affords good material for foundations. At the two foundations furthest from the river the bed of gravel is about 18 feet thick; but at the other two it is much reduced in thickness, and is only met with at a depth of 16 feet below the mean water level of the Seine, being overlaid moreover with soft and permeable deposits, and in these cases it became necessary to employ caissons sunk by the aid of compressed air. The piers are numbered 1, 2, 3, 4, and are respectively north, east, south, west; the east and south piers are the two furthest from the river, which here flows from north-east to south-west. At these two piers the gravel was met with at a depth of 23 feet. At the north and west piers the sinking was carried through the thinner gravel, and the foundations were made on the underlying bed of fine sand. Each of the four foundations consists of four component piers, which in general are erected on a mass of concrete 32 feet 9 inches long, 19 feet 8 inches wide, and 6 feet 6 inches thick. For one component pier in each foundation however the concrete is 46 feet long by 24 feet wide, being prolonged to the centre of the main pier, so as to form a platform for the elevator

machinery. Each component pier is built with one face vertical towards the centre of the tower, the outer corresponding face being inclined at the same angle as the column of the tower; the two other faces are vertical and parallel, and the top has been made at right angles to the outer face and therefore normal to the springing of the column. Two bolts, about 4 inches diameter and 4 feet 10 inches apart, are built to a depth of 20 feet into the piers, and are secured to mooring plates 8 inches deep. The concrete used was Boulogne cement; the bedstones on the tops of the piers are from the quarries of Château-Landon, and have a crushing strength of about 17,500 lbs. per square inch, whilst the maximum load to which they are exposed does not exceed 427 lbs. per square inch. The load on the ground beneath the masonry of the piers is from 3·0 to 3·4 tons per square foot. The centres of the four component piers of each foundation are 49 feet 2½ inches apart, and the four foundations form a square of about 412 feet side. The work on them lasted about six months, during which 40,000 cubic yards of earth were excavated, and 16,000 cubic yards of masonry completed.

The erection of the lower portion of the columns was effected without difficulty, and the only appliances employed were derricks and winches. The former, though 72 feet in height, were of the simplest possible construction and were made of timber. The four standards, placed one at each angle of the four columns, measure about 31 inches on a side, and were delivered on the ground in lengths weighing from two to three tons; these were handled by means of the derricks, and were bolted one upon the other as the work advanced; the standards were connected by the permanent cross-bracing, which held them in position and consolidated the structure. The bolts by which the various pieces were first connected together were afterwards replaced by rivets, as soon as it was ascertained that the different parts of the work were in their proper places. When a height of 50 feet was reached however, this plan had to be abandoned; and for the remainder of the work to the summit cranes were employed which were fastened to the work and carried up as it proceeded. These cranes consisted of a long arm, turning on a pivot, and mounted on a frame in the form of a triangular pyramid

upside down; the pivot supported a long vertical post, to which the crane arm was hung at about half its length; and the post carried a platform, from which the crane was worked; at the bottom of the frame was another small platform. As the work of building up the columns advanced, there was erected within each of them an inclined path following the same angle as the column, and consisting of two girders, the upper flanges of which were intended to serve as a roadway for the elevators; the upper flanges of these girders were pierced with a series of holes at equal distances apart to allow of the crane being fixed to them at any desired height. Similar holes were made in the lower framework of the crane, which could thus be bolted to the girders and held securely in place. As soon as all the pieces within range of the crane had been raised and riveted, the crane itself was moved upwards: a strong iron cross-beam, through the centre of which passed a screwed bolt, was secured at its ends to the two elevator girders about 8 feet above the crane; the bolt which passed through the hole in this beam was attached to the crane, and its nut was put in place above the beam; the fastenings of the crane to the riveted work were then removed, leaving it suspended by the screw alone, so that it could be raised to its new position by simply rotating the nut on the screw; after which the crane was again secured, and the cross-beam removed. Four of these cranes were used up to a height of 380 feet, but beyond this two only were employed on a somewhat modified plan. Each crane weighed 12 tons, and had a normal working load of about 2 tons. When 98 feet height was reached, it became necessary to prevent the inclined columns from falling over by their own weight. For this purpose a strong scaffolding 100 feet high was erected on timber piles, driven into the ground to prevent settlement; by these the columns were supported on their inner sides through the intervention of sand boxes, such as are commonly used for the centres of arch bridges. These were found useful for allowing the different members to be easily adjusted when necessary. Altogether twelve stagings were erected, 20,000 cubic feet of timber being employed in their construction; this however was all the scaffolding required, for as soon as the first story was completed, which is 189 feet above

the ground, the four columns mutually supported one another. To facilitate the erection of the second story, a circular railroad was laid down on the first floor, as well as a ten horse-power portable engine working a crane, from which the chain passed through a square opening in the centre of the platform; and the ironwork when delivered on the ground was hoisted by this crane into wagons on the circular railroad, and distributed by them to the different columns, into which it was raised by the cranes already described. As the work advanced, the dimensions of the iron became lighter and the progress more rapid. A height of 380 feet was reached on 14 July 1888, where the second story is situated. From this point two cranes only could be used, and they were braced firmly together, so as to form in a manner a single structure. The time required to raise them into a fresh working position was forty-eight hours; once fixed, no further change of position was necessary until a complete panel from 30 feet to 40 feet in height had been erected. In addition to these two rising cranes and the one on the first story, another was erected on the second story, and still another on the midway platform which was constructed when a height of 643 feet had been reached. During all stages of the work movable platforms were employed which could be placed in any desired position, so as to bring the riveters within reach of their work. These platforms were protected by handrails and screens, and the precautions taken were such that one man only is said to have fallen from them during the whole course of the work.

The tower terminates at a height of 906 feet above the ground with a platform about 53 feet square; the width of the column at this level is 33 feet, the gallery being carried by brackets which project sufficiently to afford a considerable area of platform. Above the platform rises the campanile, in the lower part of which is a spacious and well equipped laboratory, intended for the prosecution of scientific researches. Four arched lattice girders rise diagonally from each corner of the tower, and unite at a height of about 54 feet above the third or top platform. By means of a spiral staircase, yet another small gallery is reached, about 19 feet diameter, surrounding

the lantern which crowns the edifice and brings the total height of the structure to 984 feet. Provision is made for protecting the structure from lightning by cast-iron pipes 19 inches diameter, which pass through the water-bearing strata below the level of the Seine to a depth of 60 feet, their upper ends being connected with the ironwork of the tower. The total weight of wrought and cast iron used in the structure is 7,300 tons, not including the weight of the caissons employed in the foundations nor of the elevator machinery. Iron, and not steel, was used in the construction throughout.

The first story, which has an area of 38,000 square feet, is chiefly occupied by restaurants. The second floor, with a surface of 15,000 square feet, is surrounded by a covered gallery 8 feet 6 inches wide, having a total length of 490 feet. The central portion of this floor is occupied by the elevator service, considerable space being necessary to provide for the ascending and descending traffic. On the top platform of the tower there is a large hall covered in on all sides with glass, from which, when the weather is favourable, a magnificent panorama is visible.

ELECTRIC-LIGHT WORKS.

The machinery and apparatus manufactured at the electric-light works of Messrs. Sautter Lemonnier and Co., 26 Avenue de Suffren, Champs de Mars, may be classed under three heads, namely electrical, mechanical, and optical. The establishment was founded in 1825 by the optician Soleil for the manufacture of the lighthouse lenses then recently invented by Augustin Fresnel. In 1852 the works passed into the hands of the present proprietors, by whom fifteen years later they were removed to their present site, where they now occupy nearly two acres.

The optical department includes the manufacture of lighthouse and beacon lights, and of reflectors and lenses of different kinds for projecting the lights. The annular prisms of glass for forming the compound lenses are received in the rough from the St. Gobain works, and are here cut to exactly their calculated dimensions. The flashing

electric-light apparatus on the top of the Eiffel tower was constructed here; owing to its height and power it has a greater range than any lighthouse hitherto erected. The construction of glass reflectors for projecting the light was commenced in 1859 on Fresnel's plan of lenticular reflectors; the first was made for Prince Napoleon's yacht, the "Reine Hortense." Ten years ago, Colonel Mangin's powerful reflector completely superseded the lenticular reflectors, and has now been officially adopted for all the large navies; as many as 1,500 have already been made at these works.

In the mechanical department are manufactured windlasses and elevators with Mégy's friction clutches, and also with governors whereby the speed is prevented from exceeding a certain limit; and with a handle which must be turned right and left for lifting and lowering with accuracy, the machine stopping automatically as soon as the handle is let go. By means of these appliances either singly or in combination, all danger in handling heavy loads is obviated. A portable cask-lifter on wheels is constructed on the same principle, for loading and unloading casks on drays, and storing them in vaults or piles.

In another shop are constructed high-speed motors for driving dynamos, including Brotherhood's three-cylinder engine, Mégy's hydraulic motor, vertical engines simple and compound, and Parsons' compound steam-turbine. Also multi-polar dynamos, including a triple compound of 600 ampères for lighting the Eiffel tower, and bi-polar dynamos of high duty. The total power of the dynamos already made at these works exceeds 17,000 electrical horse-power. Fog-horns are also made, together with the air-compressing machinery for working them. On a tower erected in the works, nearly 100 feet high, commanding the Exhibition, the Trocadero, and the Seine, are mounted three electric-light projectors of the kind used as search lights for coast defences.

BON MARCHÉ
ELECTRIC LIGHTING AND REPAIRING SHOPS.

The Bon Marché drapery store, situated at the corner of Rue de Sèvres and Rue de Bac, has grown within the last thirty-five years

from a small shop into the present mammoth bazaar. For the artificial lighting of this establishment there are employed 267 arc lights of 9 ampères, 92 Jablochkoff lights, and 2,800 Swan and Edison lamps. The electricity necessary for these lights and for driving various electric motors is generated by four continuous-current machines of 550 ampères running at 70 volts, and by twenty-four others at 70 volts; and there are eight alternating-current machines of sixteen lights each. The dynamos, as well as a number of pumps used for raising and circulating water for general purposes, such as for working hydraulic hoists and extinguishing fires, are driven by four 150 HP. engines, a pair of horizontal engines of 200 HP., a single engine of 100 HP., and another of 75 HP. All these engines are of the Corliss type, and were made by Messrs. Lecouteaux and Garnier, of Paris. Steam is supplied by thirteen Belleville boilers. The dynamos are driven by belts and shafting in the usual way; and there are clutches on the shafting, so that the machines can be driven independently, or the whole can be connected together. On account of the nature of the soil, it was necessary that the large room or cellar, for containing the engines and boilers more lately added, should be constructed so as to be perfectly water-tight; accordingly the walls and floor are of iron, and the whole is riveted together. In other parts of the establishment there are carpenters' shops, a smithy, and a small machine-shop where repairs are done; also painters' and plumbers' shops. For the prevention of fire, there are 120 hydrants and 80 extincteurs in the various parts of the building.

ELECTRIC-LIGHTING STATION AT THE PALAIS ROYAL.

The central electric-lighting station constructed at the Palais Royal by the Edison Co. is situated in the Cour d'Honneur, which separates the Conseil d'État from the Orléans Gallery; and for various reasons it was decided that the station should be wholly below the ground level, so that the court is not interfered with, excepting by the spaces necessary for lighting and ventilation. Excavations were carried to a depth of 20 feet for a length of 105 feet and a width of 66 feet; the sides of this rectangular vault

were lined by retaining walls, and the ground was made water-tight by a thick floor of béton, and was covered in with brick arches. A glazed lantern, rising about 6 feet above the level of the court, lights the centre of the machine-room, and two other small ones serve as ventilating shafts. These have been railed in and the space around them planted with grass and trees, so as to avoid any disfigurement of the court. A tunnel connects this station with a store in the Rue de Vallois, in which are placed water reservoirs, coal supplies, &c.; a large flue running in the same direction leads off the products of combustion to a chimney shaft built beside one of the large houses in the same street. The boilers, motors, and dynamo are placed in the underground station in the Cour d'Honneur. The motors, of which there are eight, are triple-expansion compounds, made by Weyher and Richemond; they are each of them 160 horse-power, and are driven at a speed of 160 revolutions per minute. The boilers are of the Belleville type; they are five in number, and are worked to a pressure of 170 lbs. per square inch, which is reduced to 141 lbs. in the high-pressure cylinders of the engines. The water is obtained from the Seine, from the Canal de l'Ourcq, and from a well 115 feet deep; and is stored in three large reservoirs. The pumps are driven by two electric motors, furnished with current from the central station. The dynamos, of which there are eight, are of the Edison type, and are mounted on rails in such a way that their position can be fixed exactly by means of regulating screws. The following are the leading particulars of these machines: power 125 volts and 800 ampères, equal to 100,000 watts; armature, speed 350 revolutions per minute, outside diameter 24·80 inches, length 31·50 inches, divisions in the collector 40, resistance 0·0054 ohm, weight of copper 418 lbs.; magnets, resistance 4·25 ohms, maximum exciting current 29·5 ampères, weight of copper 627 lbs.; electrical efficiency 96·5 per cent. The method of distribution consists of three conductors, fed by the dynamos coupled in series, which in number are equal to the groups of lamps. By this method, a considerable economy in the weight of the conductors is secured. The cables are all laid under ground, and supported on porcelain insulators; the

total length of conductors is over 6 miles. Wherever a branch lead is taken off to a house, the joint is enclosed in a metallic box which contains the union and fusible contacts. This box is kept under lock and key, and any individual service can be isolated without trouble. The amount of lighting supplied from this station comprises at the present time about 6,000 lamps.

ELECTRIC LIGHTING AT THE GRAND OPERA HOUSE.

The electric lighting machinery is placed in the large cellars beneath the front steps of the building. It comprises five Belleville boilers, which supply steam to a 250 horse-power Corliss engine working at 60 revolutions per minute, a 100 horse-power engine by Armington and Sims working at 300 revolutions per minute, and five 140 horse-power compound condensing engines by Weyher and Richemond working at 160 revolutions per minute, besides two 20 horse-power engines by the same makers for driving the condensers. With the exception of the two last, the other seven engines are all employed for driving dynamos on the night service. For the day service alone a 40 horse-power portable engine by Weyher and Richemond is employed, working at 85 revolutions per minute, and supplied with steam from its own boiler. The total power provided thus amounts to 1,130 horse-power. The current-producing machines comprise fifteen Edison dynamos for general lighting purposes; one alternating-current Gramme dynamo for supplying twenty-four Jablochkoff candles; and one small Edison dynamo employed for working a centrifugal pump which raises water from a well. The number of incandescent lights in regular use amounts to 7,000.

HYDRAULIC MACHINERY AT ST. LAZARE STATION, WESTERN RAILWAY.

St. Lazare Station covers an area of 27 acres, and is laid out upon the side of a hill; it extends northwards from the Rue St. Lazare to the Boulevard des Batignolles with a rise of nearly 70 feet; at the southern end, where the station buildings are situated, the

rails are nearly 18 feet above the street level, whilst at the northern end the railway passes through a tunnel at a depth of nearly 52 feet below the street level. The southern half of the ground, forming the space between the Rue St. Lazare and the Pont de l'Europe, is occupied by the passenger station, general offices, and courtyards, and the Terminus Hotel, which forms the frontage to the Rue St. Lazare. The fourteen passenger platforms, of which six are for main-line trains and eight for suburban traffic, all start from one main platform extending across the whole width of the station ground, parallel to the Rue St. Lazare. North of the Pont de l'Europe, under which all the lines of rails pass, the ground is occupied by three coke platforms, each furnished with a hydraulic crane, and by the goods station and sidings, the hydraulic accumulators and pumps, and the electric-light shop. The new goods station was constructed about 1884, and owing to the rails being here nearly 33 feet below the street, it is made in two stories, the upper of which is at the level of the street. The heavier goods received in the station below for delivery in Paris, or at the street level above for despatch by rail, are raised or lowered by two hydraulic wagon-lifts; and smaller lifts are provided for lighter articles. At the upper story there are four longitudinal lines of rails, connected by three transverse lines, with a turntable at each crossing; and the loaded wagons are shifted by means of hydraulic capstans. Between the longitudinal lines of rails are paved roads, platforms, and horse and cattle quays, provided with weighing machines, hydraulic cranes, capstans, and lifts, so that loading and unloading can everywhere be going on simultaneously. The accumulator is loaded to give a pressure of 745 lbs. per square inch at the upper story, and the cranes there placed can lift from $1\frac{1}{2}$ to 5 tons. The exhaust water is returned into a reservoir, whence it is pumped back into the accumulators. The principal hydraulic work consists in raising and lowering the loaded and empty wagons from one platform to the other; about 200 lifts are made per day, and the maximum rate is 40 wagons per hour. Each of the wagon hoists is provided with three hydraulic rams, which can be used either singly or two at a time, or all together, according to the load dealt with.

At the end of a number of the local lines in the passenger station is a turntable mounted on a traverser, to facilitate transferring the engine from the front end to the tail of a train on its arrival. The traverser is worked by two horizontal hydraulic cylinders, which by means of chains haul it across from the up to the down line, stopping midway for the engine to be turned end for end on the turntable, which is done by means of a chain and hydraulic capstan.

For raising and lowering the hand-barrows loaded with passenger luggage between the level of the courtyard and that of the train platforms, a hydraulic chain elevator has recently been put into use. It consists of three inclined planes, round each of which passes an endless chain driven from the upper pulley at a speed of about 70 feet per minute by two pairs of small hydraulic engines. The chains are provided with transverse blocks for engaging the barrow wheels, and are kept constantly moving before the departure and after the arrival of a train; and the trucks are wheeled one after another on to the inclined planes, where their wheels are caught by the blocks on the chains, by which they are carried up to the train platform. The departing traffic is raised by the two outer of the three inclines, while the arriving luggage is lowered by the middle chain, which is driven in the reverse direction.

The hydraulic power station is at Batignolles, at the northern extremity of the goods station, whence are laid mains communicating with the six accumulators which are placed wherever the water power is made use of. There are two of these accumulators at Batignolles, which regulate the pumping machinery, and are loaded to give a pressure of 745 lbs. per square inch. The whole of the hydraulic work was carried out by the Fives-Lille Company, under the superintendence of the engineers of the Western Railway.

PRIMARY BATTERIES.

The works of MM. Perreur-Lloyd, situated at 118 Rue de Vaugirard, are devoted to the manufacture and working of primary batteries for generating electricity, which can be used for lighting, for the supply of motive power, or for electrolysis. The batteries

or generators are all of the same make, each consisting of a trough constructed of any material that will resist heat and acid; lava, of which the trough can be made in a single piece, has been found the best, although the troughs are sometimes built up of separate plates joined together.

The generator consists of two portions, in the upper of which are placed the electrodes, while the lower serves as a reservoir of the battery solution; the whole is divided by vertical plates of glass into a number of compartments, each of which forms a separate element of the generator. The elements consist of flat porous cells, communicating with one another, in which are suspended tapering carbon plates, thickest at top; between the cells are interposed plates of iron, copper, or some other metal, which constitute the soluble electrode. The lower half of the vessel, forming the reservoir of battery solution, communicates directly with the upper half containing the electrodes; and these can accordingly be brought as close together as is desired, while yet employing a much larger quantity of the exciting solution than of the more concentrated depolarising solution contained within the porous cells. For the efficient working of the apparatus it is important that the two solutions should become exhausted at the same time, whereby the manual labour of emptying and filling is diminished. As the exciting solution in the spaces between the cells becomes neutralised, it becomes also more dense and sinks to the bottom of the vessel, while the fresher and lighter portion rises and so maintains a uniform action. Above the generators are placed large reservoirs, in which the exciting and depolarising solutions are prepared; and by means of pipes provided with stopcocks the generators can readily be emptied and replenished. Whenever the circuit to the accumulators is closed, sulphates or chlorides begin to be formed in the generators; and the nitrous vapours given off are condensed, and are used over again when the solution is sufficiently concentrated to serve as the depolarising solution.

Whilst the electric current is being generated in the primary batteries and stored in the accumulators, metallic salts of

considerable commercial value, such as sulphates and chlorides of copper, iron, zinc, manganese, nickel, tin, &c., are being formed in the generators; these salts can either be sold or be used in the manufacture of other more remunerative products. The particular salt produced depends upon the metal which constitutes the soluble electrode, and the acid used as the exciting solution; and these are therefore selected according to the metallic salt that is most in demand, and to the price of the metal and acid employed. It thus becomes sometimes profitable even to work the generators for the sake of the salt obtained: in which case the value of the electricity stored in the accumulators may be accounted as extra profit, while the electricity itself retires into the rank of a by-product.

One of the best applications of these batteries is to the production of sulphate of copper, which is obtained very easily, inasmuch as copper dissolves rapidly in a solution of sulphuric acid as soon as ever the electric current is passed through it. The results obtained in this way are so remarkable that scrap brass and other impure copper can be thus treated so as to yield electrolytic copper and zinc. Under this head an industry of considerable importance has already been developed.

PORTABLE-RAILWAY AND ROLLING-STOCK WORKS, PETIT-BOURG.

The railway works of MM. Decauville at Petit-Bourg near Corbeil 21 miles south of Paris, are situated between the Seine and a branch of the Paris Lyons and Mediterranean Railway; they thus have the advantage of water carriage on the one hand and of railway transit on the other. They comprise three long ranges of low buildings, each of which represents a separate department: in one the permanent way and portable way are made; in another the ironwork for the rolling-stock is prepared, and the locomotives are built; the third is the carriage and wagon shop. Between these two latter rows of sheds, and connected with them by a series of low-pitched roofs, is a transept running nearly the whole length of the factory; this covers a railway dock which communicates direct by a siding with the railway

outside the works. All or nearly all of the manufactured products converge to this dock, and are there loaded into trucks for distribution to various parts of the world; in this manner about 120 tons of railway material are sent out of the works daily. Throughout the works, over the open ground and within the covered sheds, lines of Decauville railway extend in all directions, illustrating the admirable manner in which this narrow-gauge portable railway lends itself to factory use. Twenty acres are enclosed within the surrounding fence; the length of the factory is 524 feet, and the width of the two buildings connected by the central transept is also 524 feet. No great amount of power is required to drive the machinery at the works; probably all the engines in use do not collectively make up 300 horse-power; for although there are 540 machine-tools of all kinds constantly at work with 950 workmen, only some of them are heavy. The boilers used throughout are those of MM. Weyher and Richemond of Paris; and one feature of the place is the adoption of iron chimneys of the Creusot model, with cast-iron base and 100 feet high.

About 5,200 miles of permanent way and portable way have been turned out of the workshops of Petit-Bourg; the weights adopted for the rails are 9, 14, 19, and 24 lbs. per yard, according to the purpose for which the line is intended. The lengths to which this permanent way is made up range from 4 feet 1 inch to 16 feet 4 inches, varying with the different requirements. The lightest sections are manufactured specially for agricultural purposes, for shop yards, and for certain classes of earthworks; loads as great as half a ton per axle can be safely carried upon the 9-lb. rails. A section similar to that of the ordinary flat-footed rail is adopted, excepting that the foot is somewhat exaggerated in size for the purpose of riveting on the sleepers. The weight of the built-up sections of permanent way is so small that one man can easily handle a length of the lighter kinds, while the heavier require two men for the transport of a complete length. The width of the gauge varies from 40 centimètres (15·75 inches) to 75 centimètres (29·53 inches); that most usually made is 60 centimètres, or nearly 2 feet, with rails weighing 14 lbs. per yard, and in lengths of 16 feet 4 inches; such lengths weigh less

than 200 lbs., and can easily be carried by two men. The sleepers now adopted for passenger and goods traffic as well as for heavy cannon are made of steel 4·9 inches wide and 0·2 inch thick, turned over at the edges to a total depth of 1·14 inch; the ends are turned over to the same depth and rounded. This form of sleeper combines considerable strength with lightness, and the closed ends prevent the ballast from spreading, when they are properly laid; six or eight such sleepers are riveted to each 16 feet length of permanent way. The successive lengths are joined together by fish-plates and sole-plates; one end of each rail in a length has a pair of fish-plates riveted to it, and projecting so as to clip the end of the rail in the adjoining section, to the underside of which the sole-plate is fixed. By this arrangement the sections can be turned end for end without interfering with the mode of joining them together. The construction of the portable railway and of the various classes of rolling stock to run upon it was fully described in M. Decauville's paper to this Institution in May 1884 (Proceedings, page 126).

A considerable number of sets of machines are necessary to turn out the large amount of work produced. The steel rails are first cut to accurate lengths by cold saws, two of which are mounted in the same frame, so that both ends can be trimmed simultaneously; the work of punching the holes in the foot or flange follows; and lengths required for curves are passed through ordinary bending rolls. The sleepers are made by stamping; the heavier have their edges turned over, and their ends afterwards formed under an inclined steam-hammer. Multiple drilling machines are employed for forming the holes in the sleepers, as well as in the rails; and multiple riveting machines are also used for securely fixing the different parts together. Great care is taken to ensure accuracy of workmanship; a very slight degree of inaccuracy is sufficient to cause the rejection of the work by the shop inspectors. After the lengths are completed —either for the ordinary way, for curves, or for crossings—they are brought to the painting machines, which are ingeniously constructed to cover the whole of the surfaces with a coat of red lead. The paint is led from a reservoir through a series of ducts to different

sets of brushes, vertical, horizontal, and inclined, which are caused to oscillate rapidly by means of cams, and so to distribute the paint in profusion over the ironwork. To the brushes succeed a number of revolving wipers that take off the superfluous paint, which falls into a trough below. After passing through this machine the lengths are stacked, and when dry are ready for transport.

More than a hundred different kinds of wagons are constructed for various purposes. Interchangeability has been so carefully carried out that in spite of the great variety many of the constructive details are similar in each form of wagon. Passenger rolling-stock is made to a smaller extent, though large quantities are actually turned out yearly.

The standard make adopted for locomotives is compound, on the Mallet system. These engines can run round curves of 66 feet radius; and can take a load of 17 tons up a gradient of 8 per cent. or 1 in 13; on a straight level they can haul 280 tons. The weight of the engine in working order is 12 tons, the boiler pressure is 180 lbs. per square inch, and the power developed is 85 horse-power. The Decauville Railway at the Exhibition is worked by seven of these locomotives.

With one exception nothing but portable-railway material or narrow-gauge permanent-way is produced at Petit-Bourg; this exception consists of the portable bridges designed by M. Eiffel, of which a large number have been constructed at Petit-Bourg since 1884. Seven different elementary forms are all that are required in the construction of these bridges, and as the heaviest piece weighs only 300 lbs. they are easily transported; they are designed for a maximum span of about 70 feet, and to carry a total distributed load of 16 tons; as the various elements are all interchangeable, the work of erection is simple and rapid.

CALAIS NEW HARBOUR WORKS (Plate 113).

In 1875 the total shipping entering and leaving the port of Calais was only 840,000 tons, the net weight of freight imported and exported not exceeding 215,000 tons. Despite the natural advantages

of locality with regard to England, it was impossible to anticipate any large increase in traffic until the harbour accommodation could be greatly improved; the mail service between Dover and Calais was the only one which could be run at fixed hours, and to do this the boats were of necessity small and inconvenient, while even with the greatest precautions difficulties often arose in crossing the bar, especially after a succession of easterly winds. The construction of the works which are now practically completed has wholly changed the condition of the port. By the combined action of dredging and sluicing, a minimum depth of 10 feet at the lowest tides has been obtained, corresponding to a depth of 36 feet at high water; the same depth is maintained by similar means in the inner channel between the jetties. This channel is to be enlarged by shifting the eastern jetty, and the western one will be extended in the future.

The sluicing reservoir has now an area of 220 acres at ordinary high tides; it has been excavated to a mean depth of 16 feet above datum, excepting in the centre, where a deeper channel has been made as far as the sluicing lock. The volume of water that can be stored at high tide is about 56,000,000 cubic feet, and this quantity can be discharged through the sluicing gates with a fall varying from 20 feet to 13 feet, during about three-quarters of an hour at each tide. The sluicing lock is made with five openings, each 19 feet 8 inches wide, separated from one another by piers $11\frac{1}{2}$ feet thick, and closed by balance gates turning round central vertical axes; the sill of the openings is laid at low-water level. The sluicing water is directed chiefly upon the lower part of the inner channel where a great deal of sand is deposited, and where dredging is difficult; the sand is thereby carried down to the bar, where it can be easily dealt with by the dredgers.

The new outer basin has an area of about 16 acres; its outlet faces north-west, and it is enclosed by the north-eastern and south-western quays, and at its south-eastern end by the entrance locks of the floating basin. The average width of the outer basin is 525 feet, and its depth is 11 feet below datum, excepting at the foot of the south-western quay, where a channel 23 feet deep has been cut to allow deep-draught vessels to lie alongside. This quay, which is

about 800 feet in length, and on which warehouses are built and rails laid, is specially intended for the service of transatlantic steamers that are able to load or unload at Calais during one tide without the necessity of entering the floating basin. On the north-eastern quay is built the terminal station of the Northern Railway; this quay is intended specially for the steam-boats between England and France. Its length is 1,870 feet, and there is 13 feet depth of water alongside at low tide; four groups of landing stages are provided, so that four Channel steamers can load or unload simultaneously.

Communication between the outer port and the floating basin is effected through two locks of equal length but unequal width. The wider has a clear width of 68 feet 10 inches, and the level of the lowest part of the invert is 69 inches below the French marine-chart datum. Gate chambers are formed in the masonry to receive one pair of gates at the upper end of the lock, two pairs of gates at the lower end, and one pair in the middle; the first pair serve as flood gates, and the other three pairs as ebb gates. The gates are so placed as to give a maximum clear length in the lock of 436 feet. The narrower lock is 45 feet 11 inches in width, and is also provided with four pairs of gates, which are so arranged as to give a maximum clear length of 449 feet; this length can be divided into two unequal lengths by means of the intermediate gates.

The lock gates, constructed by MM. Cail and Co., are about 32 feet high and 43 inches thick for the flood gates, and 51 inches thick for the ebb gates; they are framed in iron, the principal members being eight horizontal girders placed about 52 inches apart, and connected to vertical frames at the ends as well as to four intermediate standards. The air-chambers in these gates extend from the bottom to the level of the sixth horizontal girder. The total weight of each wing of the pair of gates is 85 tons for the wider lock, and $50\frac{1}{2}$ tons for the narrower.

Four turning bridges are constructed across these locks to provide for the public traffic, two at the lower end and two at the upper; all are similar in construction, differing only in length, which for the wider of the two locks is 159 feet, divided into a span of 92 feet, and a counterbalance of 67 feet; the length of the smaller bridges is

117 feet, divided into a span of 69 feet, and a counterbalance of 48 feet. The two main girders of the bridges for the wider lock are placed 17 feet apart from centre to centre; and outside each is a footpath 4 feet wide, carried on angle-iron and plate brackets which are riveted to the main girders. The underside of the main girder is horizontal, and the upper flange is curved so that the depth is reduced from $11\frac{3}{4}$ feet in the centre to 9 feet at the ends. When the bridges are in place for public traffic they are supported upon the centre pivot and by three bearings at the ends, which are arranged so as to lock the girders and keep them in position; but when they are opened the locking bearings at the ends are withdrawn, and the bridge is then supported on the pivot and on rollers placed beneath the end of the counterbalance. The weights are so adjusted that each roller has to carry a maximum load of only five tons. The total weight of each of the larger bridges is 265 tons, including a counterweight of 45 tons added to the counterbalance; the weight of each of the smaller is 190 tons, including a counterweight of 30 tons.

The area of the floating basin is nearly 30 acres, including the small basin which forms its inner end. Its width is 557 feet near the entrance and 393 feet at the inner end; the width of the small basin is 229 feet; the depth is about 20 inches below the lock sills. The total length of quays around this basin is 4,820 feet, and around the inner basin 1,150 feet. The width of the western quay is 328 feet, and of the eastern 459 feet; sheds and warehouses have been constructed on these areas, and all the quays are laid with lines communicating with the Northern Railway. At the inner end of the floating basin is a graving dock, which can accommodate vessels up to a length of 495 feet, and of any tonnage likely to enter the port; its width was determined upon with a view to receiving the largest paddle-wheel steamers likely to be employed on the Channel service. The pumping machinery is capable of emptying the dock in less than three hours under the most unfavourable conditions.

The basin intended for the service of inland navigation has an area of about 10 acres, and about 5,248 feet length of quay wall. It is connected with the new floating basin by two locks, and at the

other end with the Citadel lock, the old port, and the Pierrettes and Calais canals. The Marck canal has been diverted in such a way that it can be discharged into the outer harbour. The Calais canal has also been improved, its course having been straightened and its depth and width increased, so that at present it can pass vessels as large as 400 tons, which is the heaviest tonnage that can be accommodated by the waterways in the north of France and between Belgium and Paris.

Hydraulic machinery is employed for all purposes where power is required, such as working the sluices, lock gates, bridges, capstans, &c.; the power is distributed from a central station H, Plate 113, on the north side of the locks between the outer harbour and the floating basin. The sluices, which are of hard wood sliding in polished grooves cut in the granite facing of the adjoining walls, are raised and lowered by the direct action of an ordinary vertical hydraulic press with differential piston. The lock gates are opened or closed by hydraulic presses and tackle; two presses for each leaf of a gate are placed side by side, one for opening and the other for closing the gates. The controlling valve, worked by a hand-lever, is so arranged as to form a communication at the same time between one of the cylinders and the pressure main, and between the other cylinder and the exhaust main; and the arrangement of the admission and exhaust ports is such that it is possible to vary at pleasure the relation between the tension on the acting chain, and the resistance offered by the tail chain. A small auxiliary press placed at the end of the closing cylinder forces the closing piston to the bottom of its stroke after the process of opening the gate, in order to pay out the remaining slack of the closing chain, so that it may sink to the bottom and let vessels pass over it. By this arrangement the opening and closing of the gates can be effected very rapidly by one person. The machinery for working the turning bridges comprises the pivot and its connections, the tilting presses, and the locking apparatus. The pivot turns within a cast-iron hydraulic cylinder filled with glycerine, which is maintained at a pressure of 710 lbs. per square inch. The tilting presses act direct by vertical plungers. The presses for turning the bridge haul chains passing in

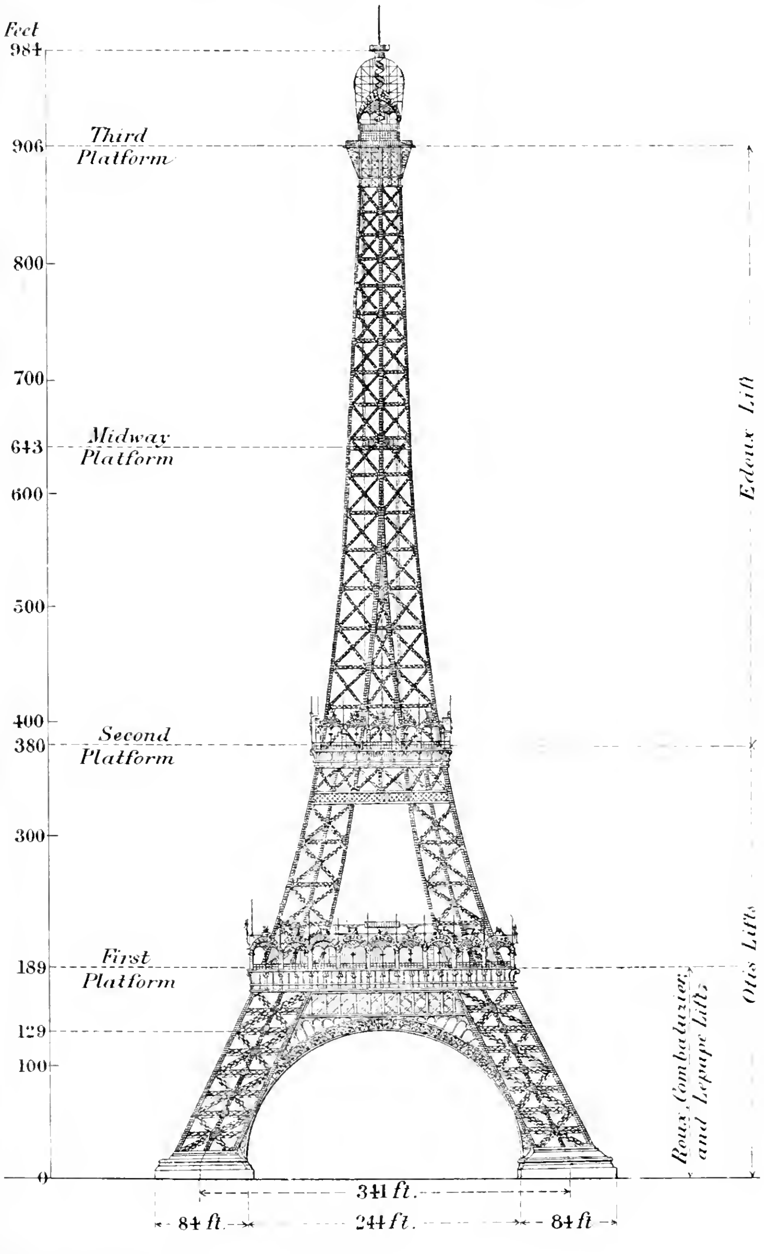
opposite directions round a cast-iron drum placed underneath the girder.

Four capstans to haul one ton each are placed along each of the outer sides of the lock; three others of five tons and two of one ton are fixed upon the central wall dividing the locks. They are employed for handling the vessels passing through, and are driven by small three-cylinder hydraulic engines; but they can be worked by hand in case of necessity, and can also be utilized either for opening the lock gates or for turning the bridges. The central hydraulic station which supplies the water under pressure for the whole of the machinery comprises two groups of pumps, each driven by a 50 horse-power engine, and two accumulators. This part of the work was designed by M. Barret, engineer of the Marseilles Docks, and carried out by the Fives-Lille Company. The designs for the new harbour works were prepared under the direction of MM. Stoecklin, Plocq, and Guillain, engineers-in-chief of the maritime works of the Pas de Calais, by M. Vétillart, engineer of the port of Calais; and have been carried out under the successive supervision of these four gentlemen as engineers-in-chief, and of MM. Vétillart and Charguéraud as resident engineers.

EIFFEL TOWER LIFTS.

Plate 61.

Fig. 1. *Elevation of Eiffel Tower.*



(Mechanical Engineers 1889)

Scale 1/2000th

EIFFEL TOWER LIFTS.

Roux, Combaluzier, and Lepape Lifts.

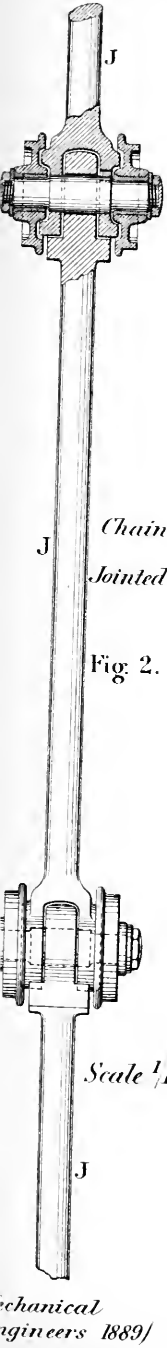


Fig: 2.

Chain of Jointed Rods.

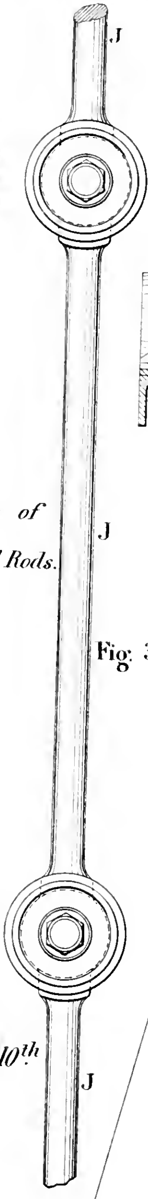


Fig: 3.

Scale 1/10th.

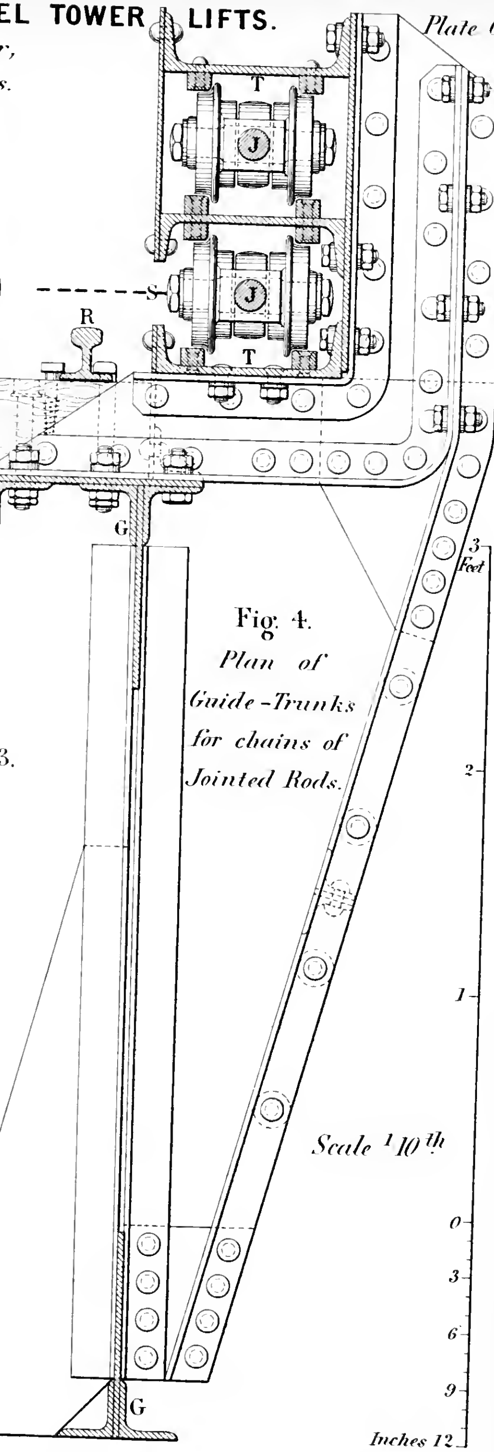


Fig: 4.

Plan of Guide-Trunks for chains of Jointed Rods.

Scale 1/10th.

EIFFEL TOWER LIFTS.

Roux, Combaluzier, and Lepape Lifts.

Fig. 5. *Side Elevation of Hydraulic Cylinder.*

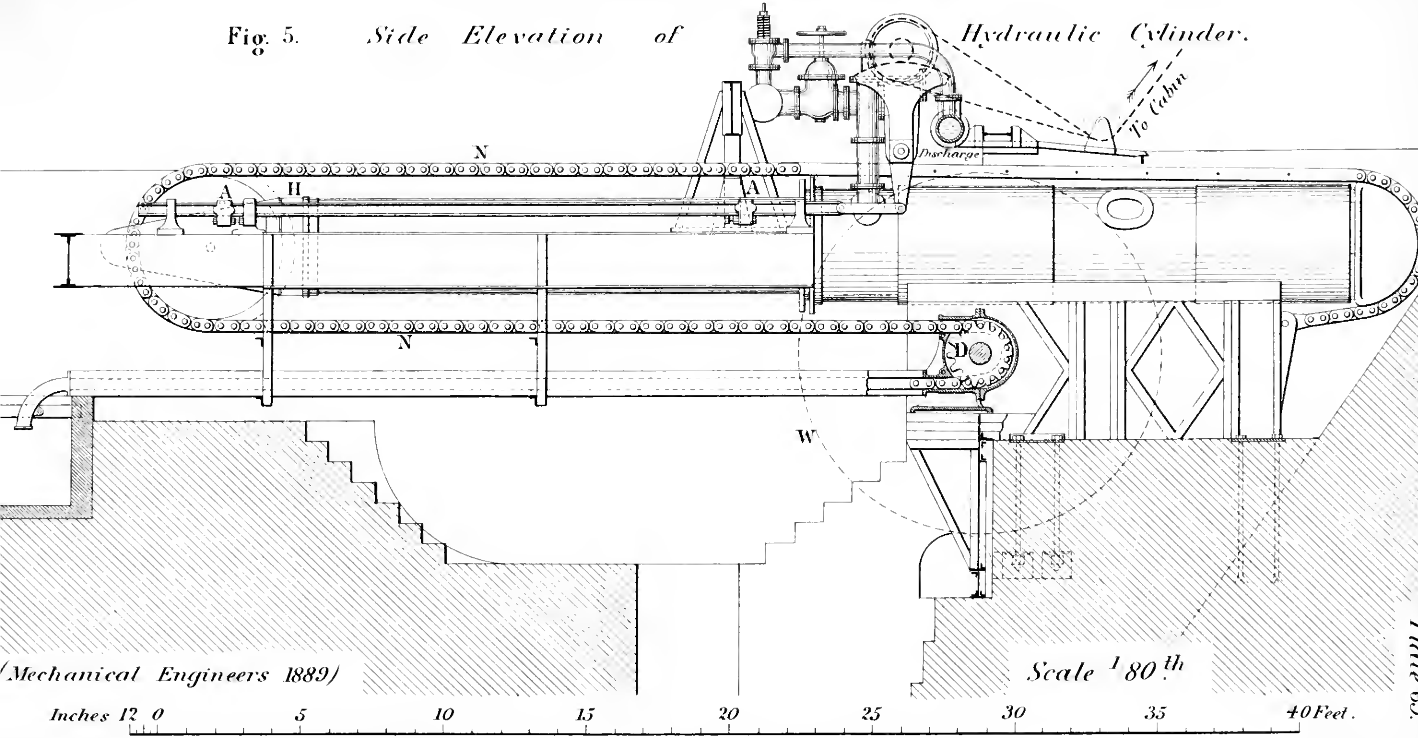
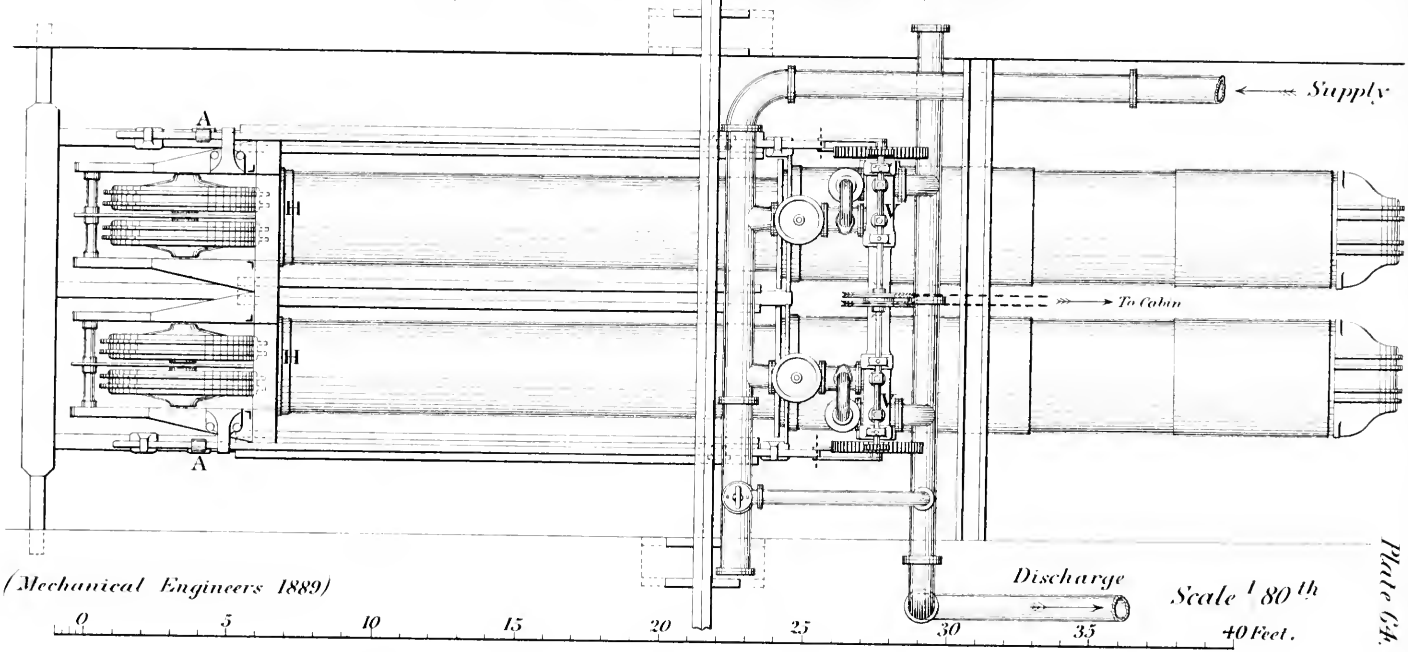


Plate 63.

EIFFEL TOWER LIFTS.

Roux, Combaluzier, and Lepape Lifts.

Fig. 6. Plan of Hydraulic Cylinders.



(Mechanical Engineers 1889)

Plate 64.

Roux, Combaluzier, and Lepape Lifts.

Fig. 7. Transverse Section through Hydraulic Plungers.

Scale 1/80th.

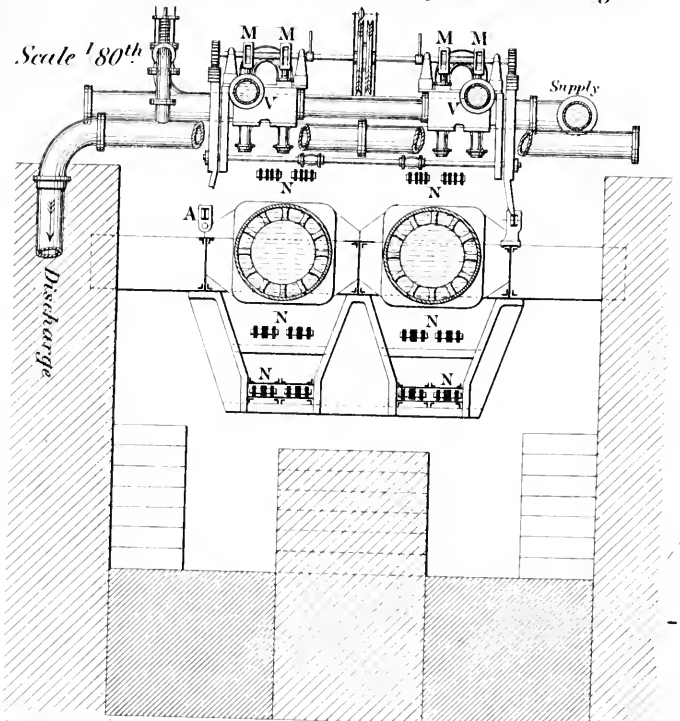
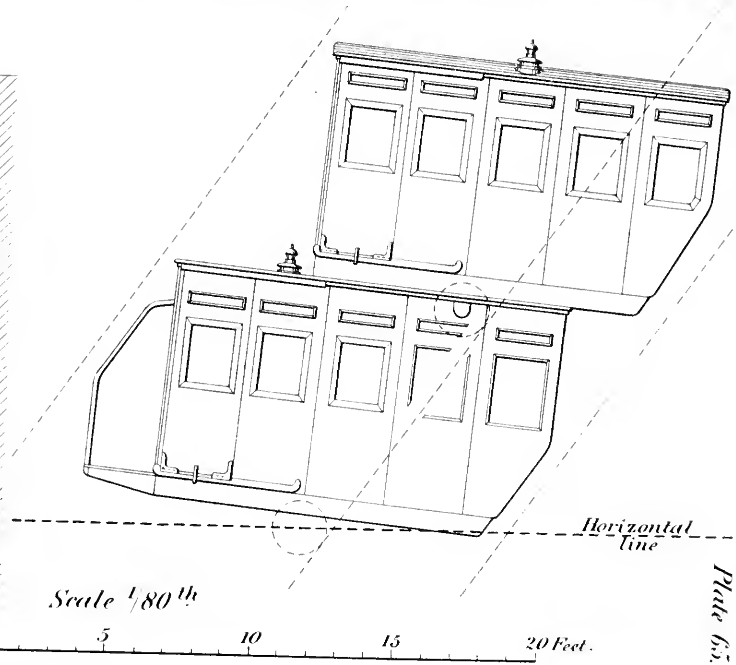


Fig. 8. Side Elevation of Cabin. Scale 1/80th.



(Mechanical Engineers 1889)

EIFFEL TOWER LIFTS.

Plate 66.

Roux, Combaluzier, and Lepape Lifts.

Water Distributor.

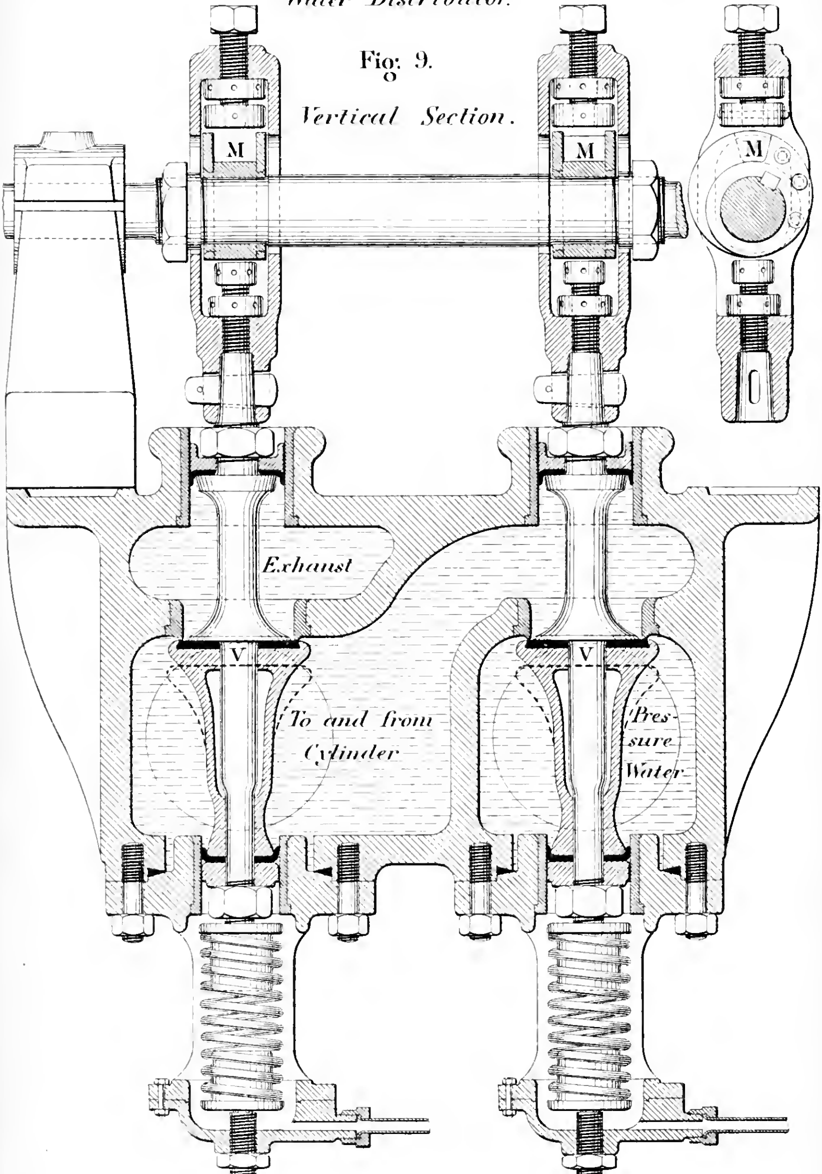
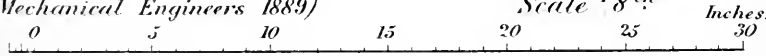


Fig: 9.
Vertical Section.

Fig: 10.
Transverse Section.

(Mechanical Engineers 1889)

Scale 1/8th

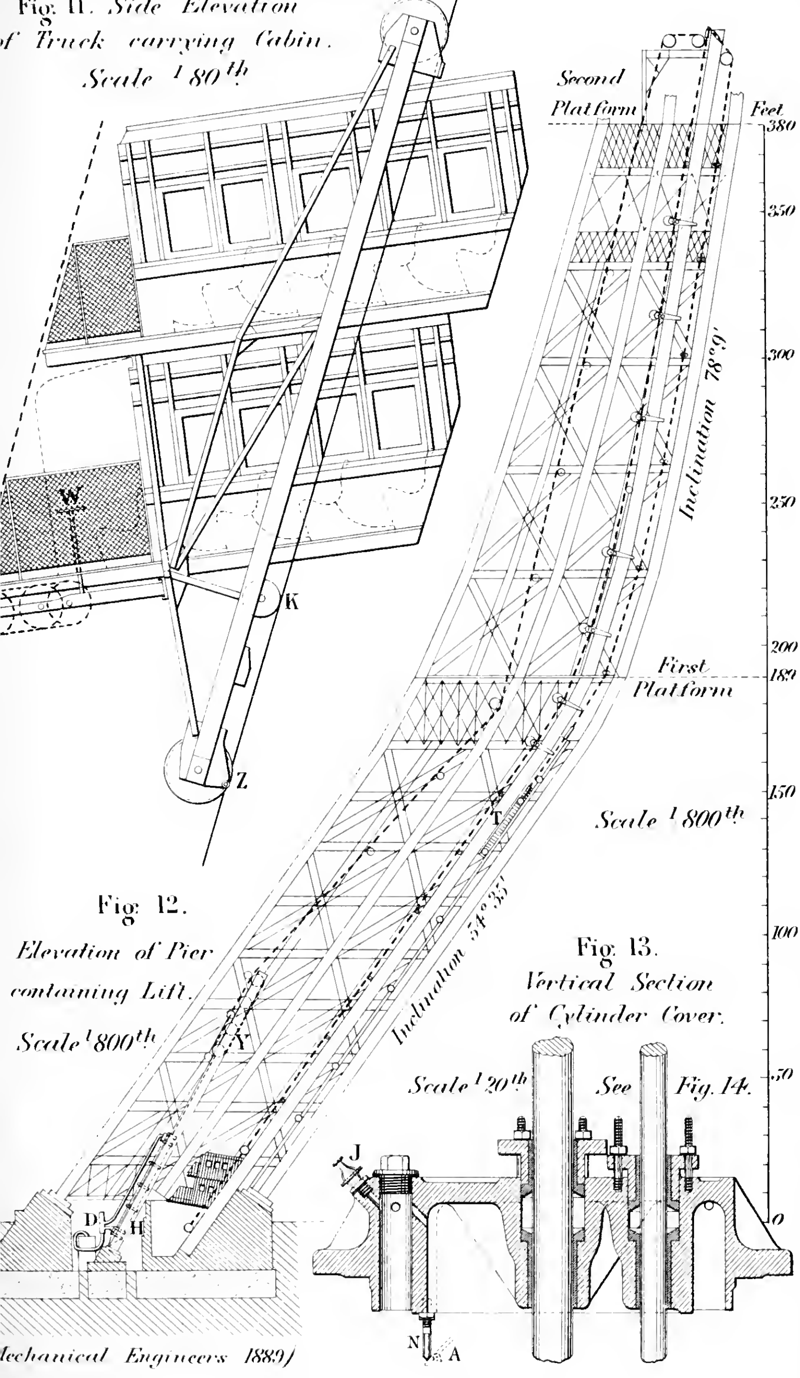


Otis Lifts.

Fig. 11. Side Elevation of Truck carrying Cabin. Scale 1/80th.

Fig. 12. Elevation of Pier containing Lift. Scale 1/800th.

Fig. 13. Vertical Section of Cylinder Cover. Scale 1/20th. See Fig. 14.



EIFFEL TOWER LIFTS.

Otis Lifts. Hydraulic Cylinder.

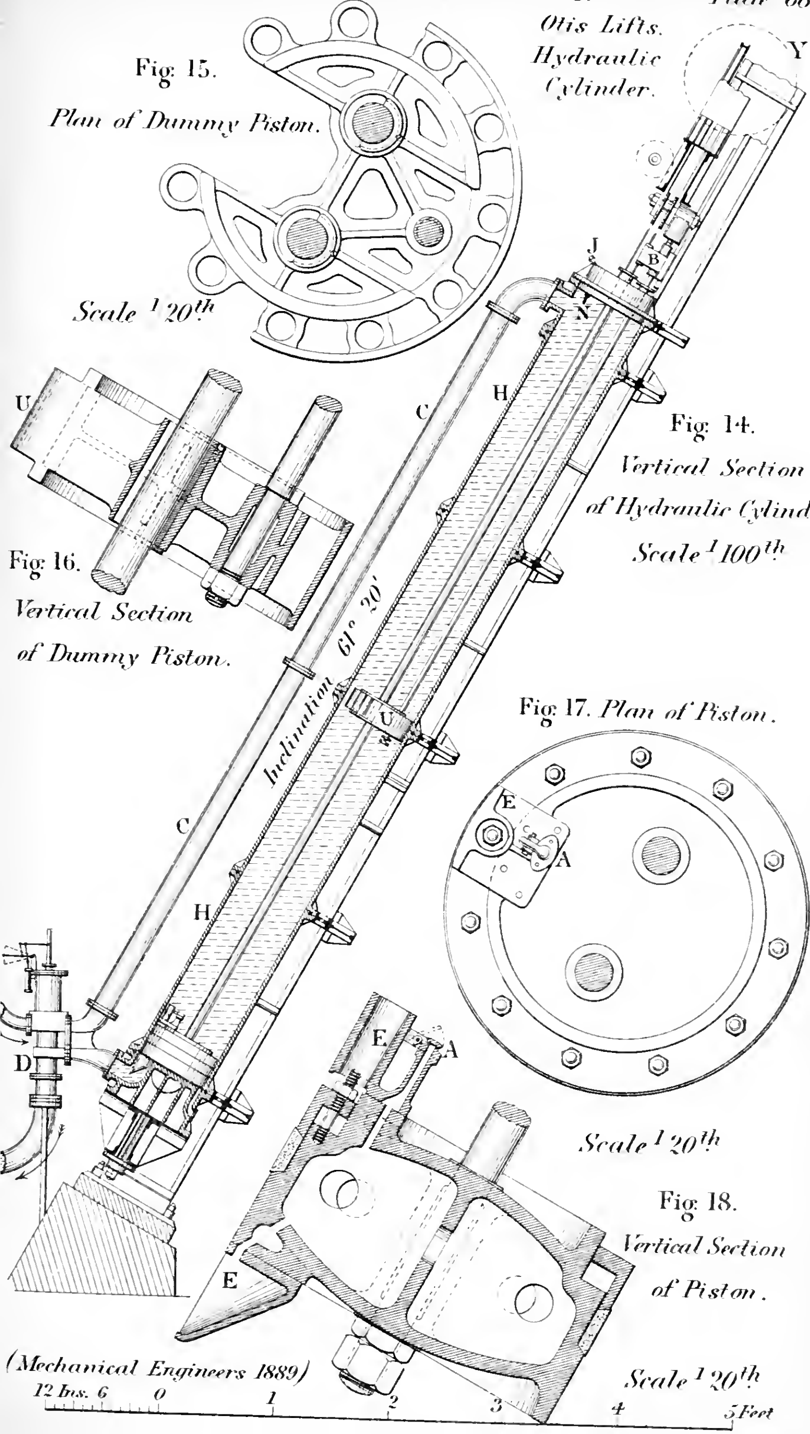


Fig: 15. *Plan of Dummy Piston.* *Scale 1/20th.*

Fig: 16. *Vertical Section of Dummy Piston.*

Fig: 14. *Vertical Section of Hydraulic Cylinder.* *Scale 1/100th.*

Fig: 17. *Plan of Piston.* *Scale 1/20th.*

Fig: 18. *Vertical Section of Piston.* *Scale 1/20th.*

(Mechanical Engineers 1889)

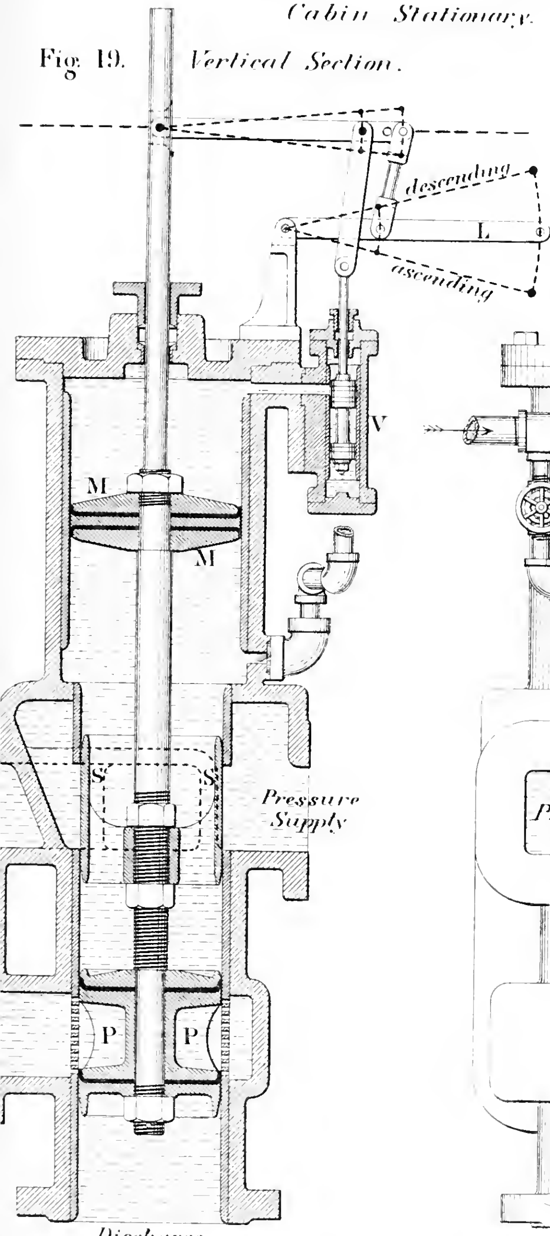
EIFFEL TOWER LIFTS.

Plate 69.

Otis Lifts. Water Distributor.

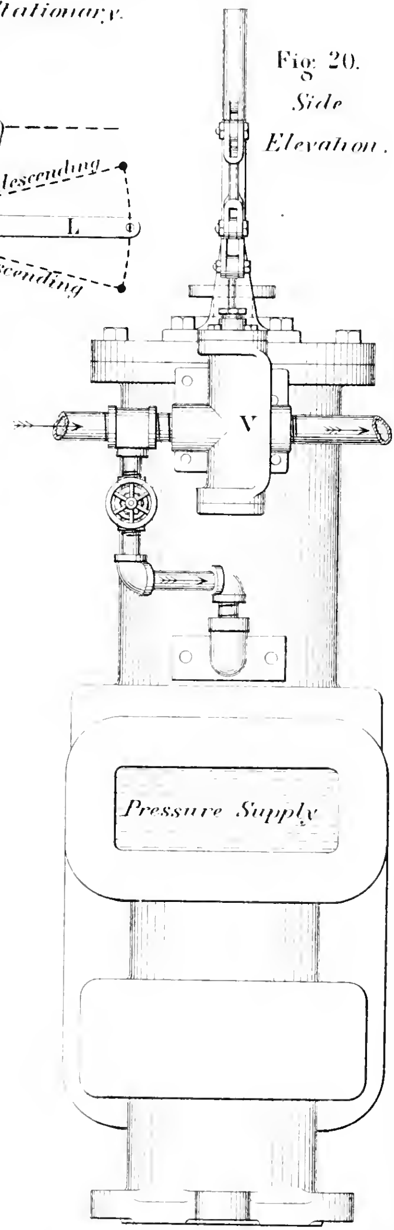
Cabin Stationary.

Fig. 19. *Vertical Section.*



Discharge

Fig. 20. *Side Elevation.*



(Mechanical Engineers 1889)

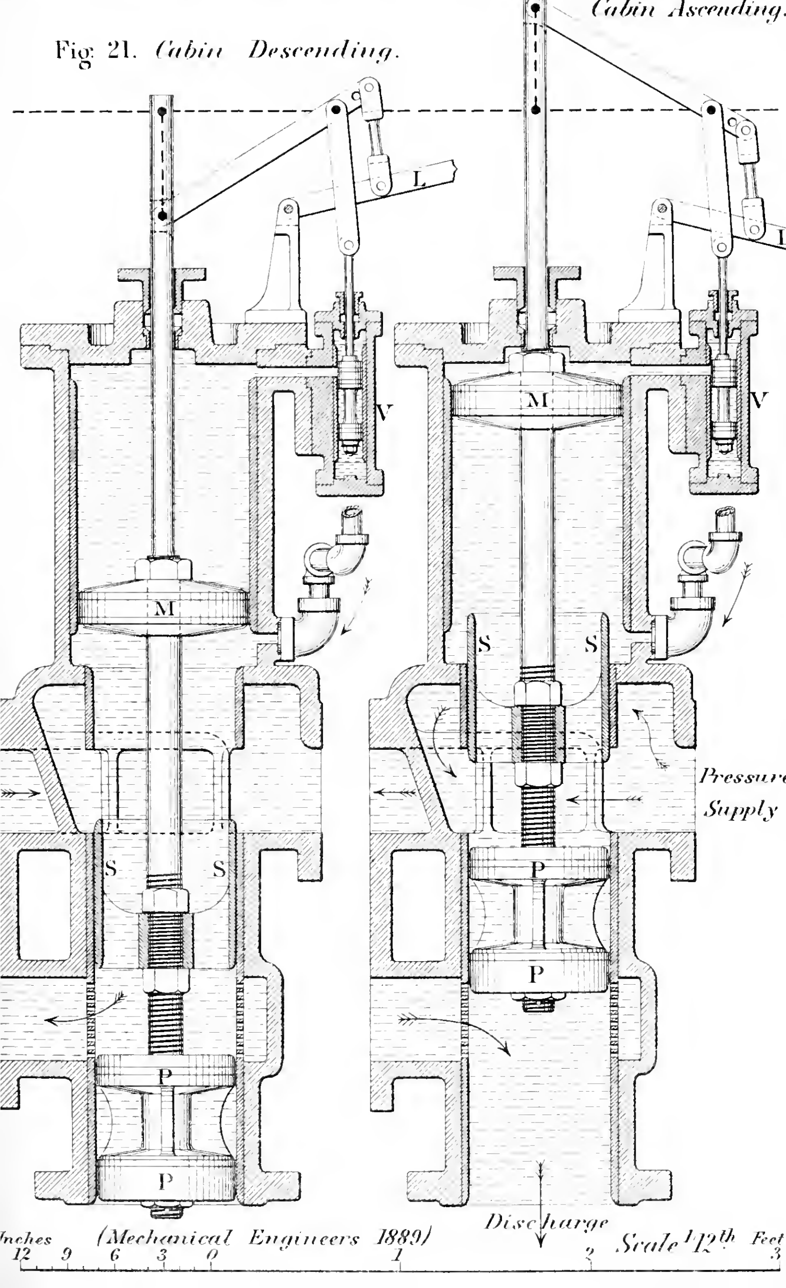
Scale 1/12th

Inches 12 9 6 3 0 1 2 3 Feet

EIFFEL TOWER LIFTS. *Plate 70.*

Otis Lifts.

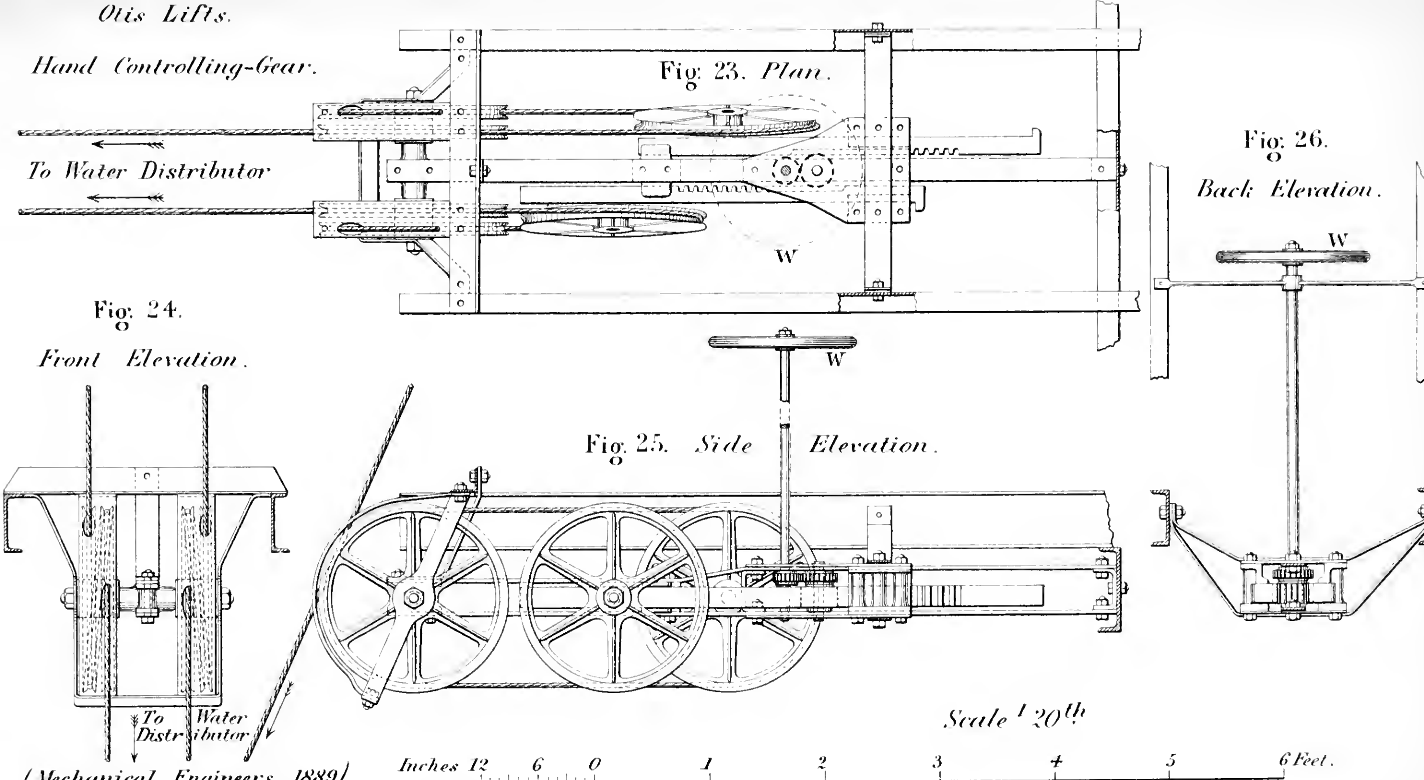
Vertical Sections of Water Distributor.



(Mechanical Engineers 1889)

Otis Lifts.

Hand Controlling-Gear.



(Mechanical Engineers 1889)

Plate 71.

EIFFEL TOWER LIFTS.

Otis Lifts. Travelling Pulley-Truck.

Fig. 27. *Front Elevation.*

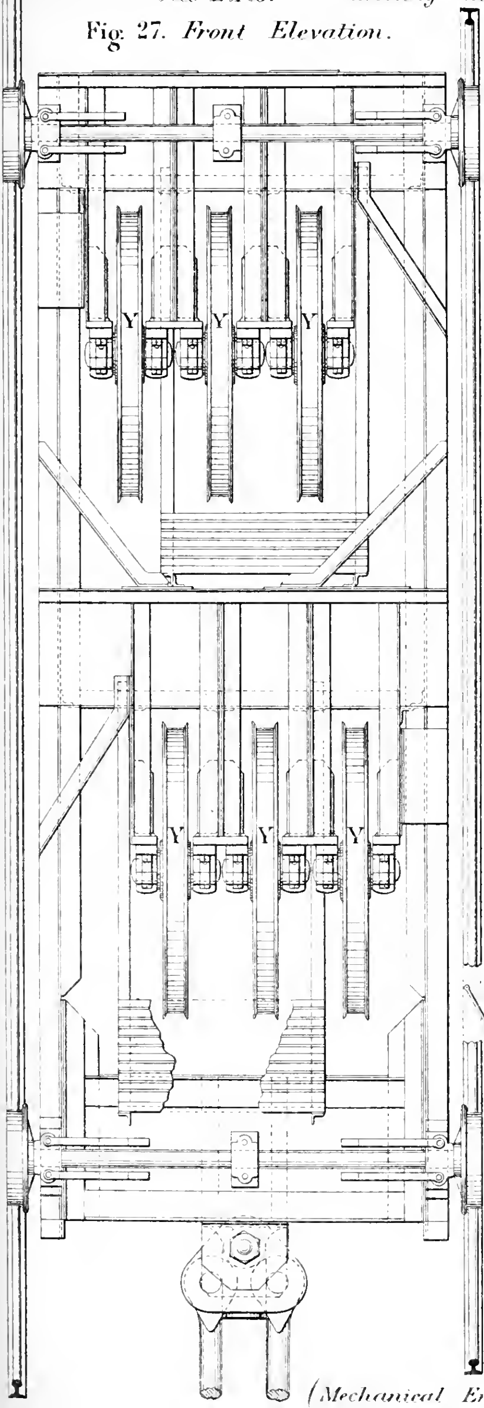
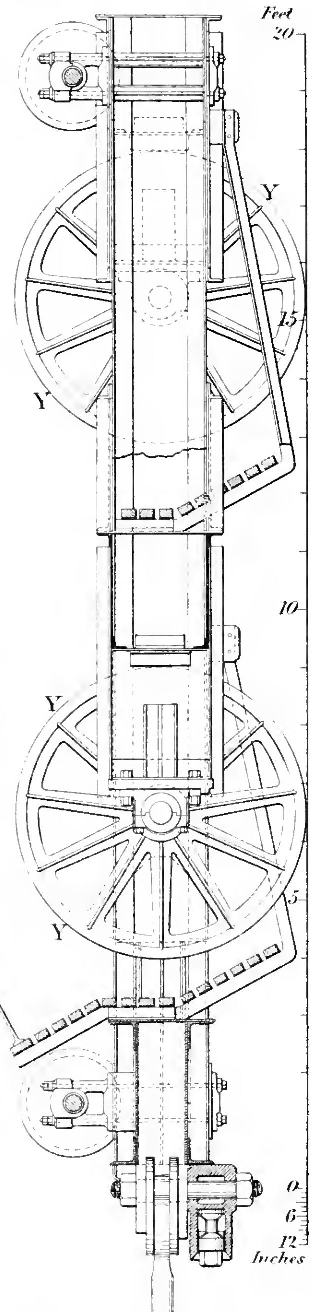


Fig. 28. *Vertical Section.*



(Mechanical Engineers 1889) *Scale 1/40th*

EIFFEL TOWER LIFTS. *Plate 73.*

Otis Lifts. Cabin Safety-Brake.

Fig: 29. *Front Elevation.*

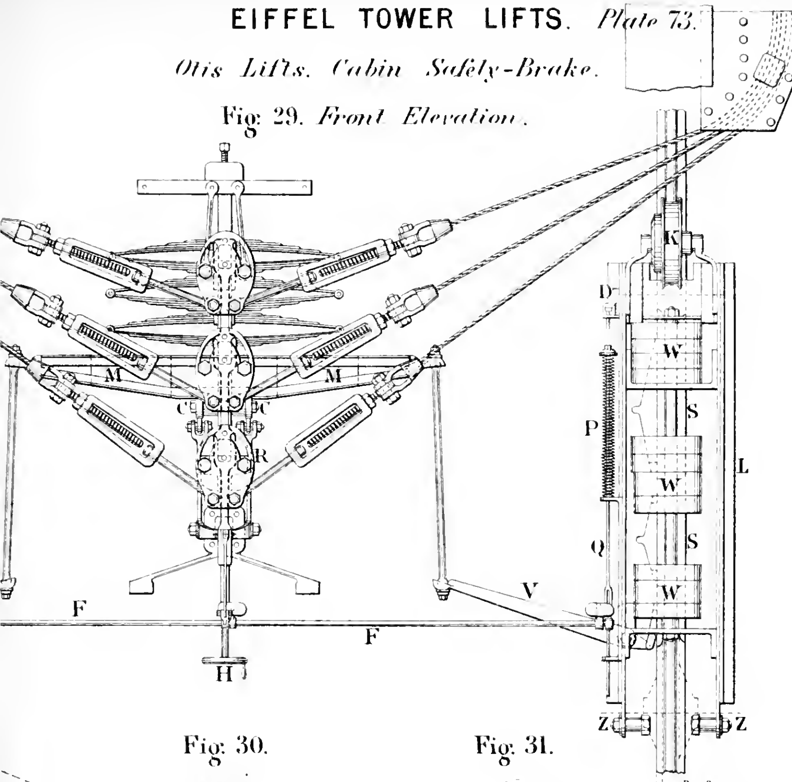


Fig: 30.

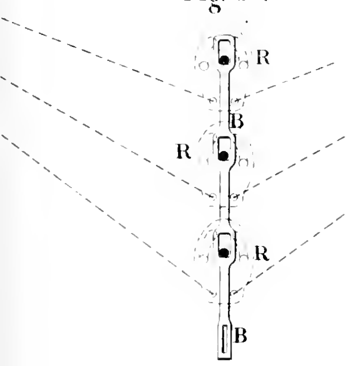
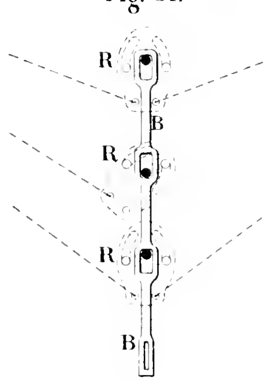


Fig: 31.



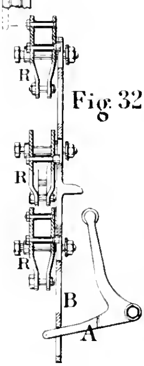
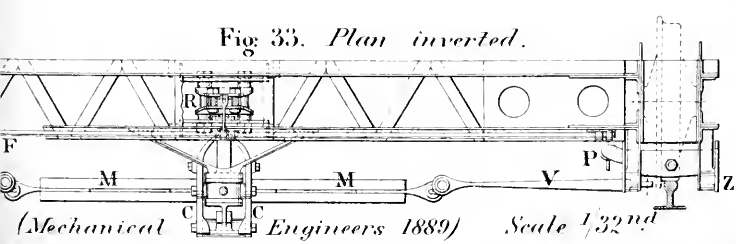


Fig: 32.

Fig: 33. *Plan inverted.*



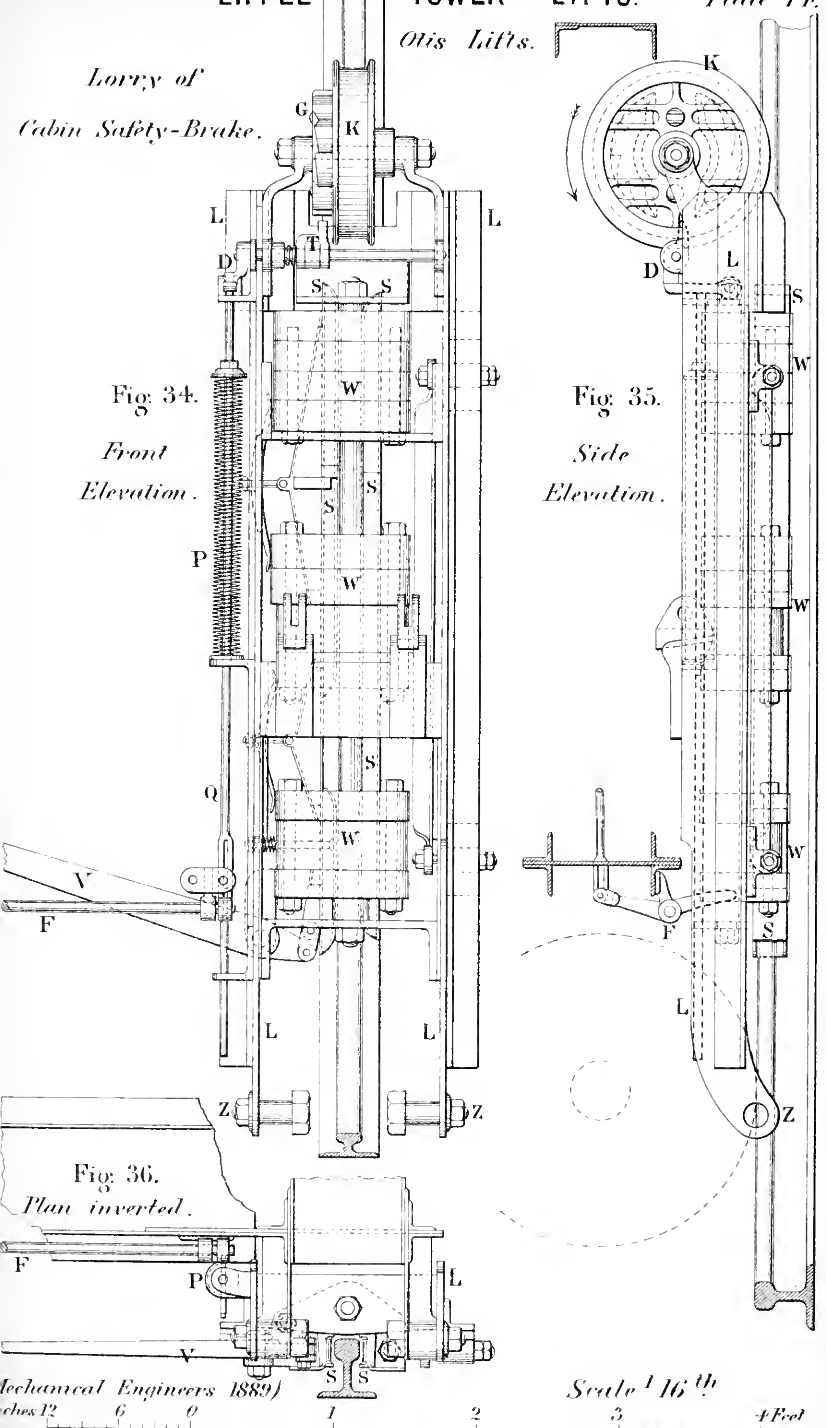
(Mechanical Engineers 1889) Scale 1/32nd

Ins. 0 1 2 3 4 5 6 7 8 9 Feet 10

EIFFEL TOWER LIFTS. *Plate 74.*

Otis Lifts.

Lorry of Cabin Safety-Brake.



EIFFEL TOWER LIFTS.

Plate 75.

Otis Lifts.

Cabin Safety-Brake.

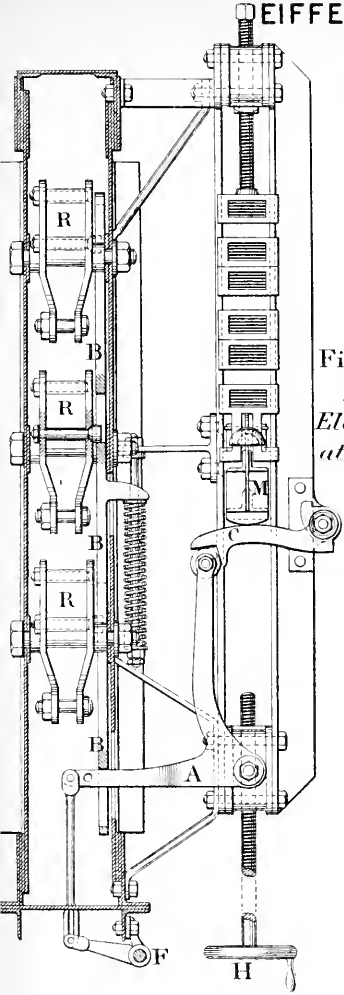


Fig. 37. *Side Elevation at centre.*

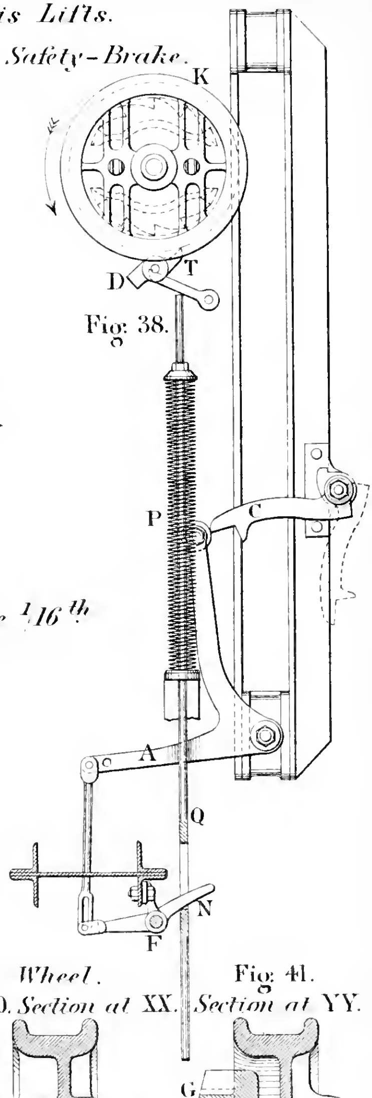


Fig. 38.

Scale 1/16th

Centrifugal Governor in Lorry Wheel.

Fig. 39. *Elevation.*

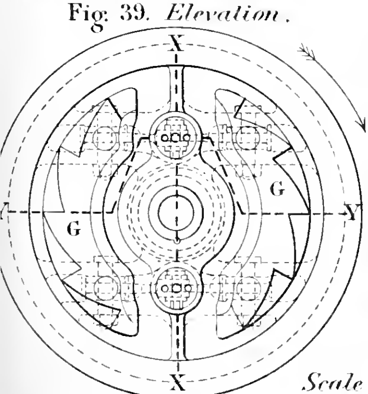


Fig. 40. *Section at XX.*

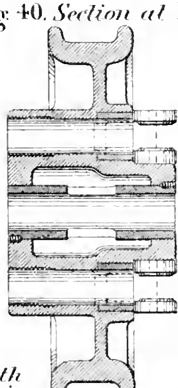
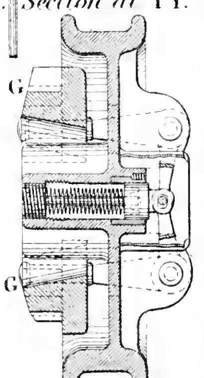


Fig. 41. *Section at YY.*

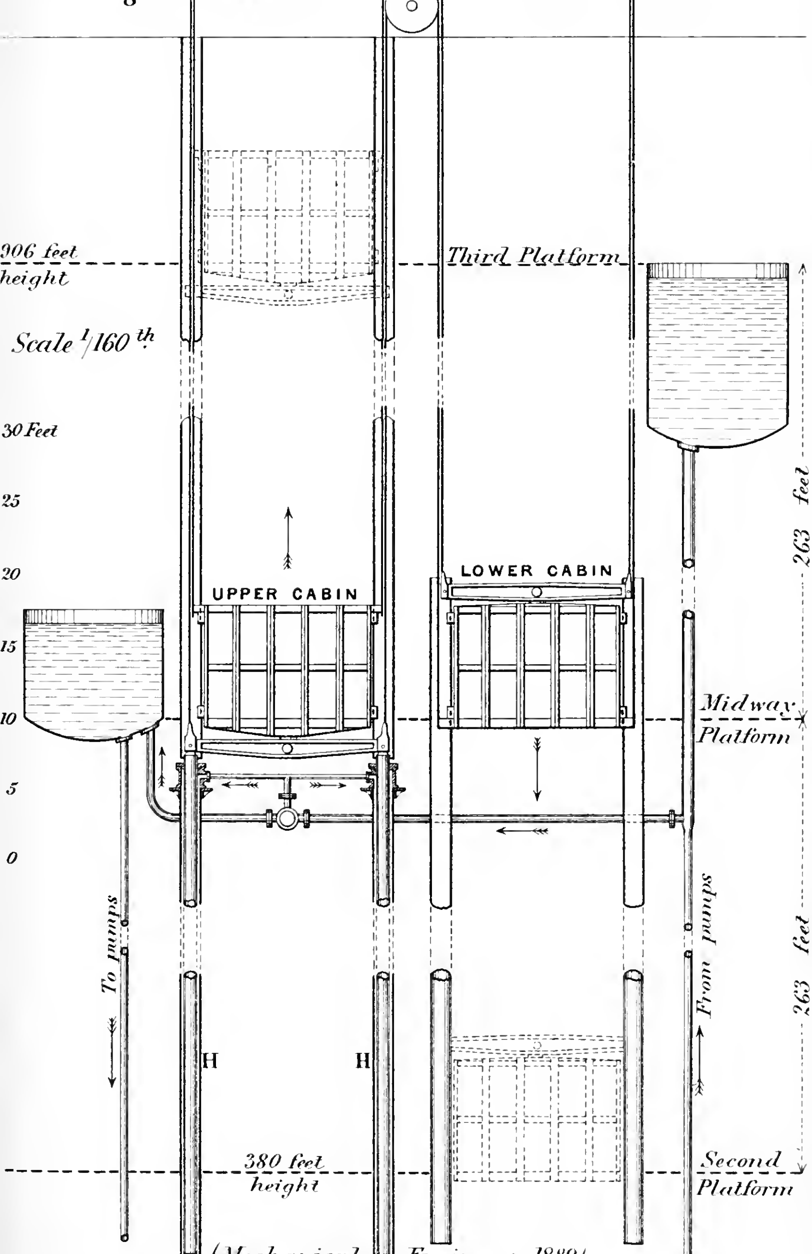


Scale 1/8th

0 5 10 15 *Inches.*

EIFFEL TOWER LIFTS. *Plate 76.*

Fig. 42. *Elevation of Edoux Lift.*



(Mechanical Engineers 1889)

Edoux Lift. Backman Brake.

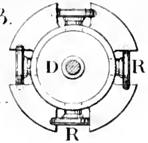


Fig. 43. Plan of Drum.

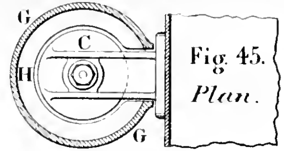


Fig. 45. Plan.

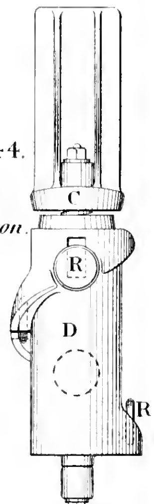


Fig. 44. Side Elevation.

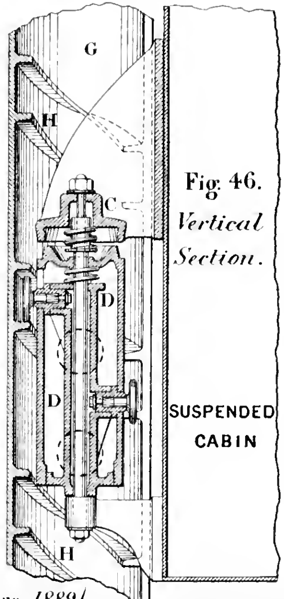


Fig. 46. Vertical Section.

Scale 1/20 th

(Mechanical Engineers 1889)

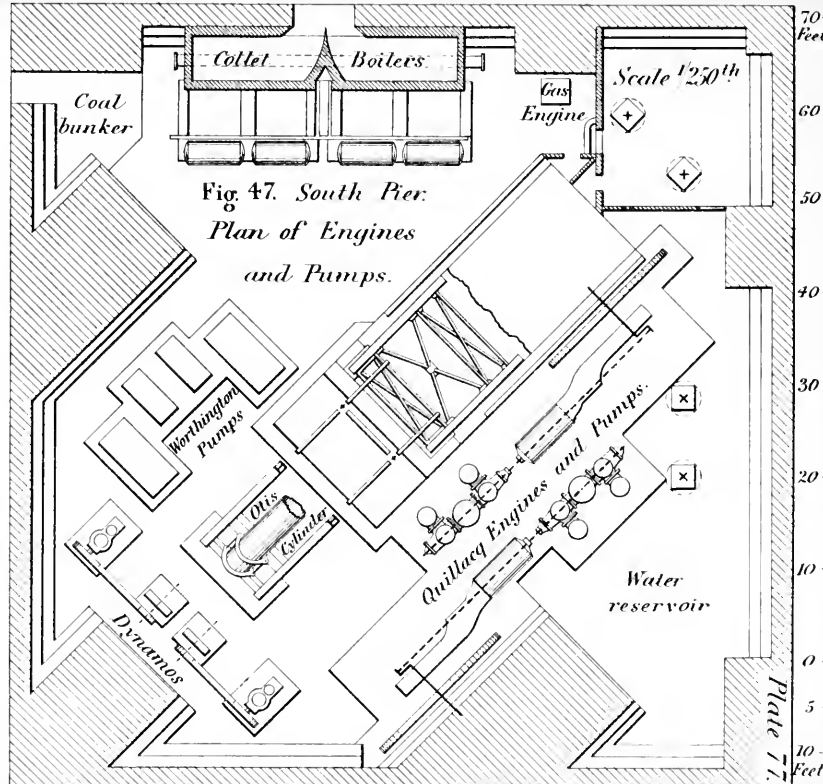


Fig. 47. South Pier. Plan of Engines and Pumps.

Plate 77.

ETHER-PRESSURE THEORY.

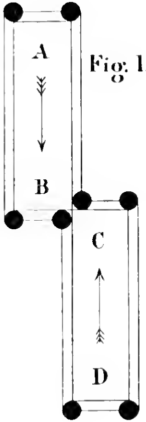


Fig. 1.

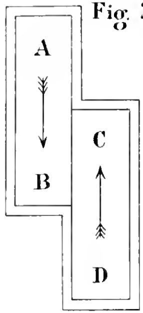


Fig. 2.

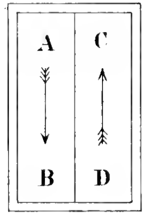


Fig. 3.

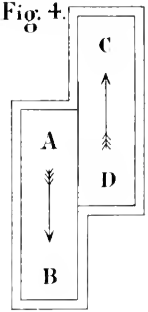


Fig. 4.

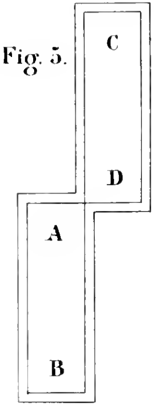


Fig. 5.

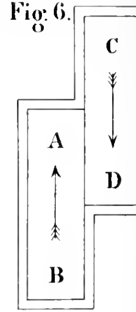


Fig. 6.

Fig. 7.

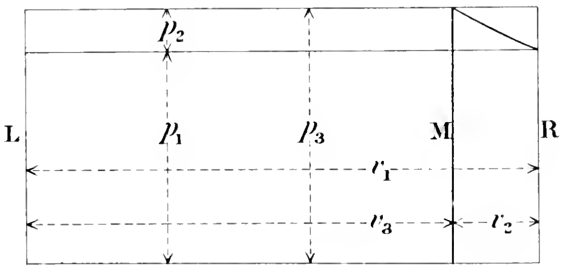
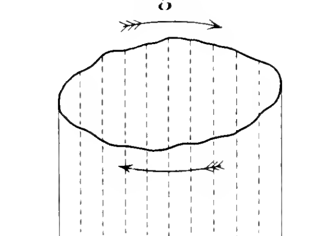
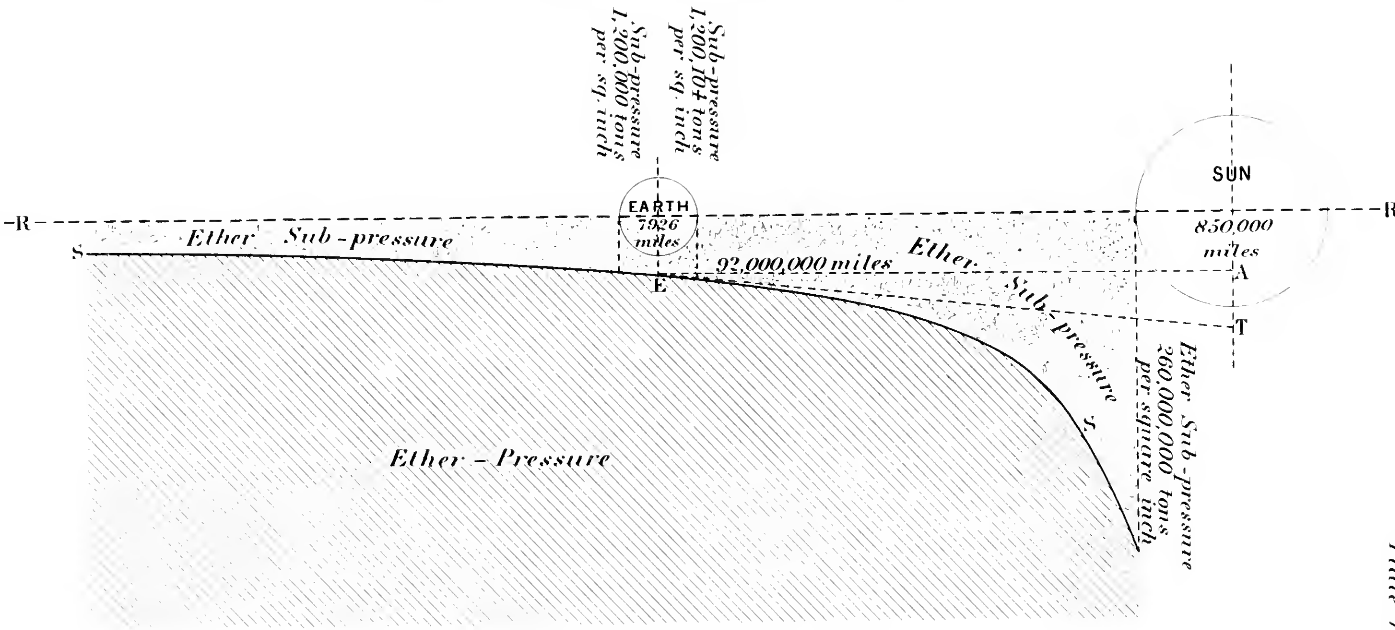


Fig. 8.



Mechanical Engineers
1889

Fig. 9. *Diagram of Ether Sub-pressure.*



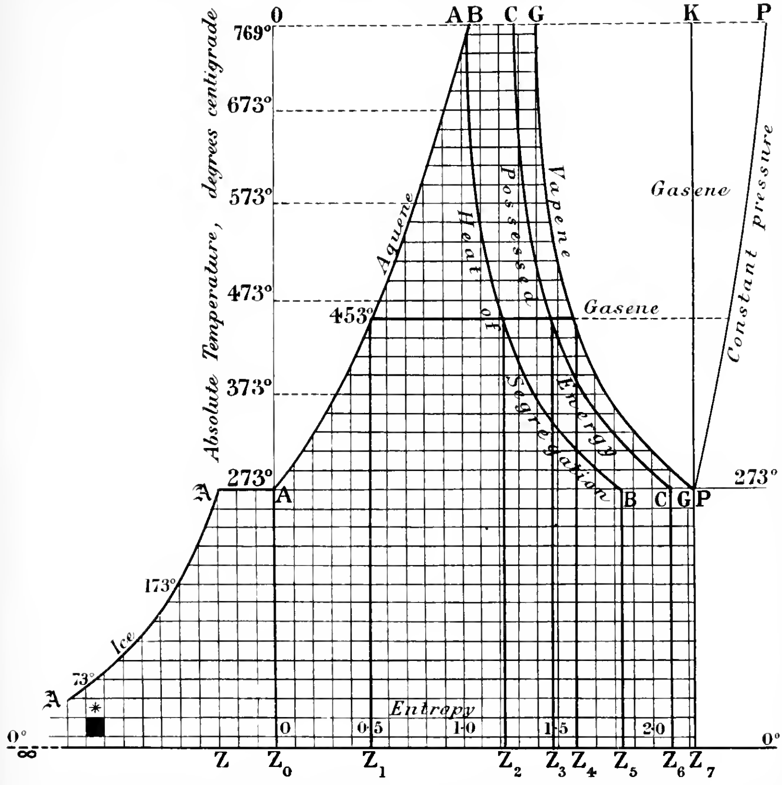
(Mechanical Engineers 1889)

Plate 79.

REGNAULT'S STEAM EXPERIMENTS. *Plate 80.*

Fig. 10.

Theta-phi Diagram for ice, aquene, vapene, and gasene.



* *The black square and each similar square represents Two units of heat.*

Fig. 11.

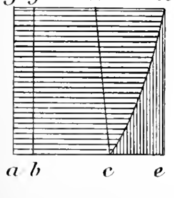
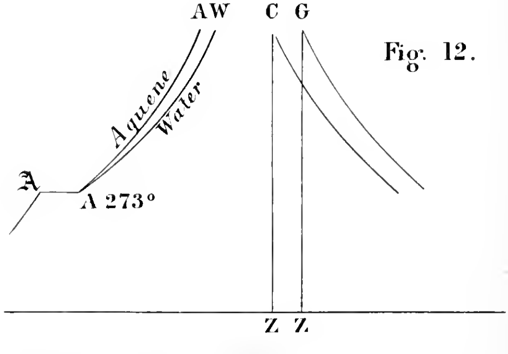


Fig. 12.



(Mechanical Engineers 1889)

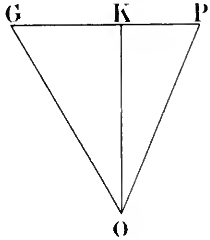


Fig. 13.

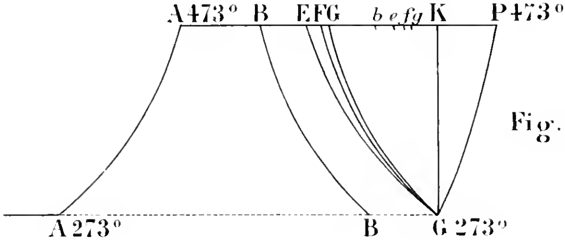


Fig. 14.

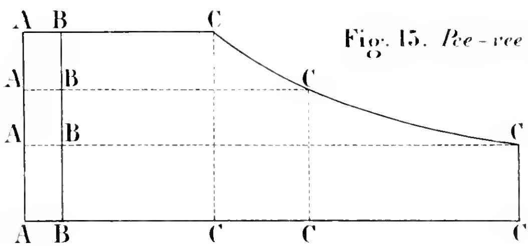


Fig. 15. *Pee-vee diagram.*

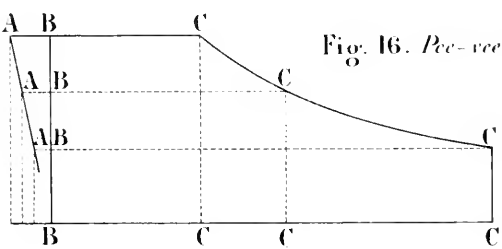


Fig. 16. *Pee-vee diagram.*

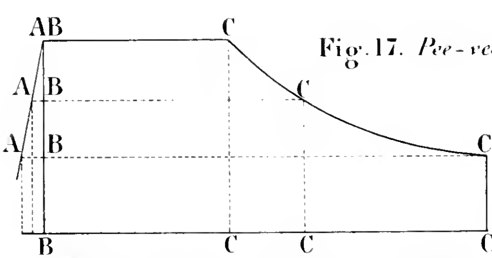


Fig. 17. *Pee-vee diagram.*

REGNAULT'S STEAM EXPERIMENTS.

Differences between Total Heat of Saturated Steam in Regnault's Experiments and by Formula.

Fig. 18. *Low Temperatures. See Table 8.*

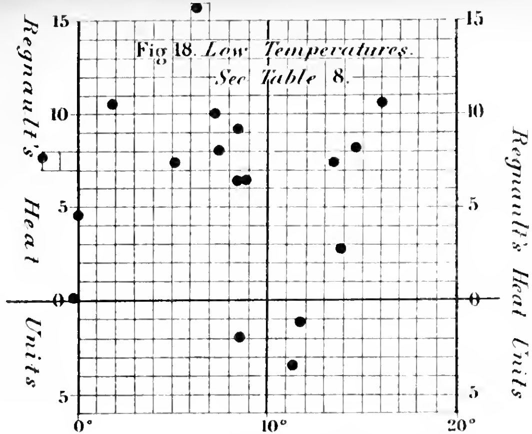
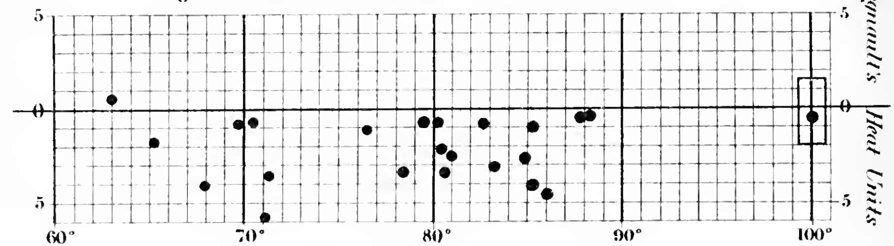
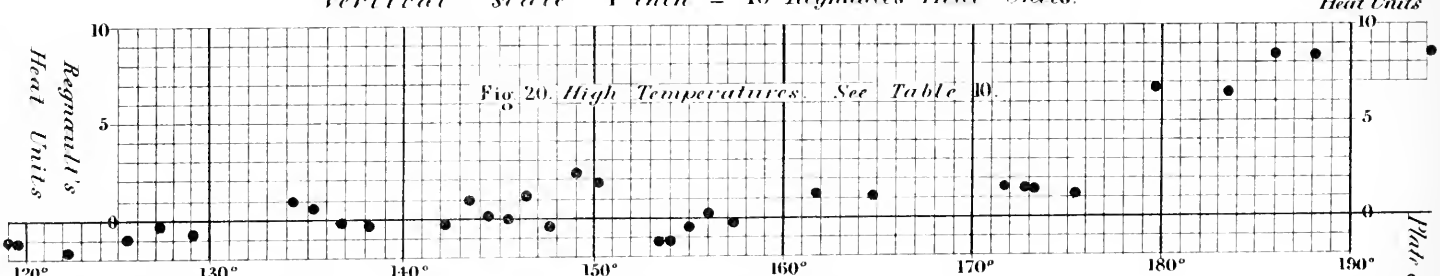


Fig. 19. *Medium Temperatures. See Table 9.*



Vertical scale 1 inch = 10 Regnault's Heat Units.

Fig. 20. *High Temperatures. See Table 10.*



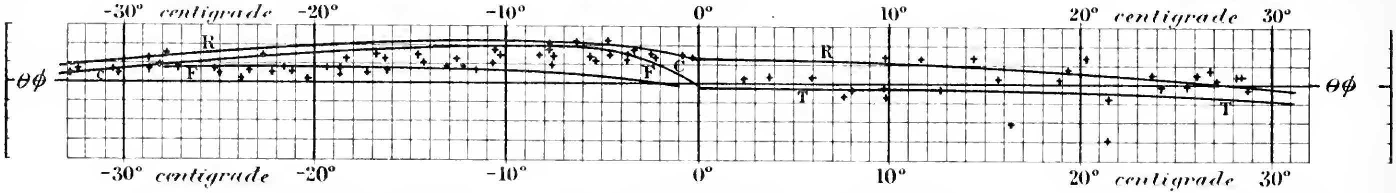
(Mechanical Engineers 1889)

REGNAULT'S STEAM EXPERIMENTS.

Fig. 21. *Differences between Steam Pressures in Regnault's Experiments and by Theta-phi Calculation.*

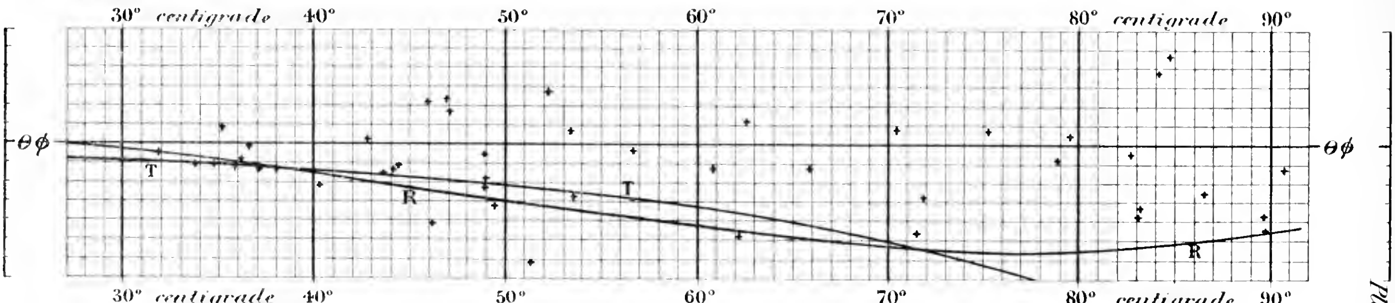
See Table II.

Continued below



Vertical scale, 1 *inch* = 1 *millimetre of mercury.* 0 1 *inch*

Continued from above



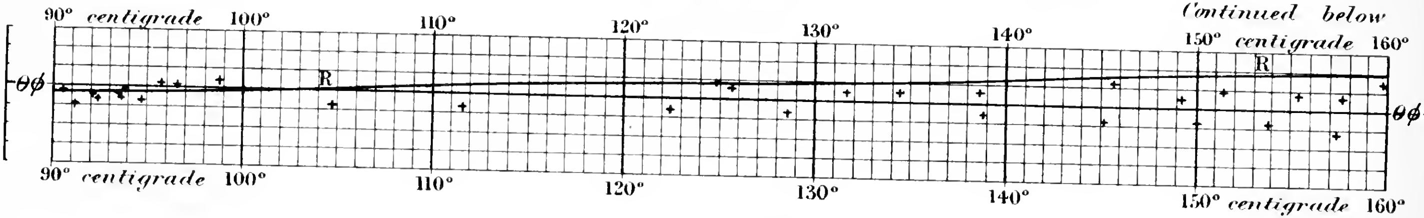
(Mechanical Engineers 1889)

REGNAULT'S STEAM EXPERIMENTS.

Fig: 22. *Differences between Steam Pressures in Regnault's Experiments and by Theta-phi Calculation.*

See Table 11.

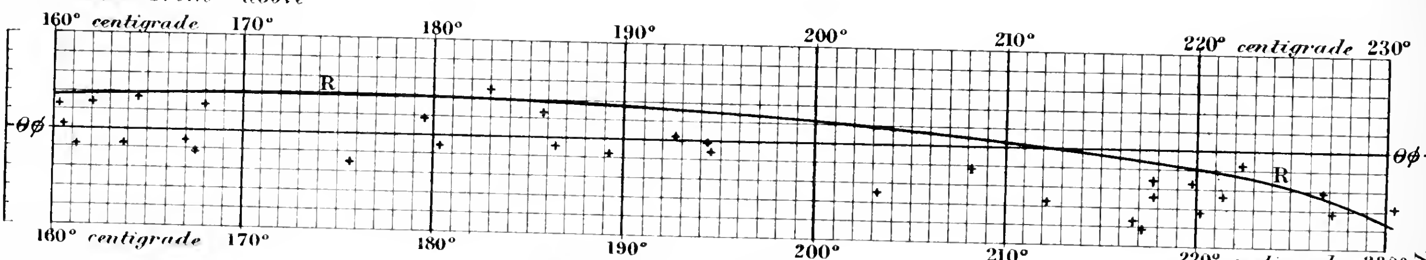
Continued below



Vertical scale, 1 inch = difference of pressure due to 1° difference of temperature.

0 — 1 inch

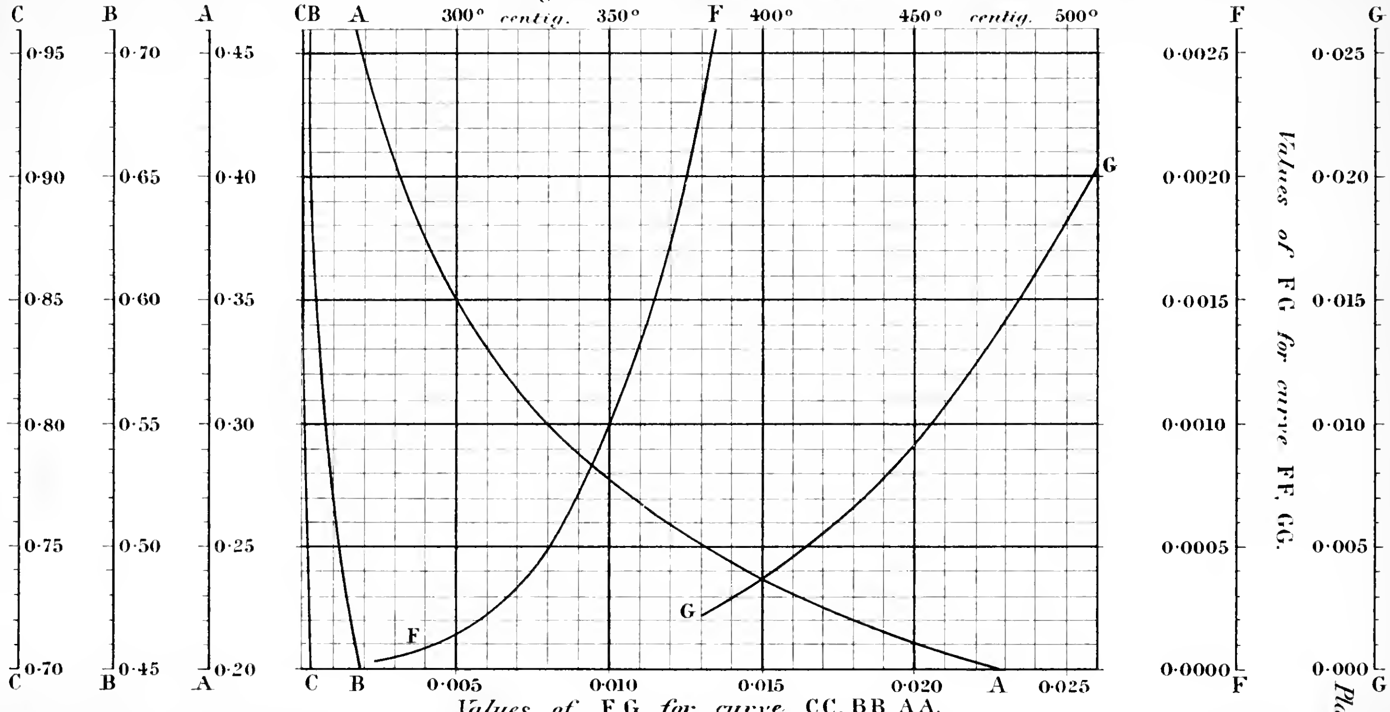
Continued from above



(Mechanical Engineers 1889)

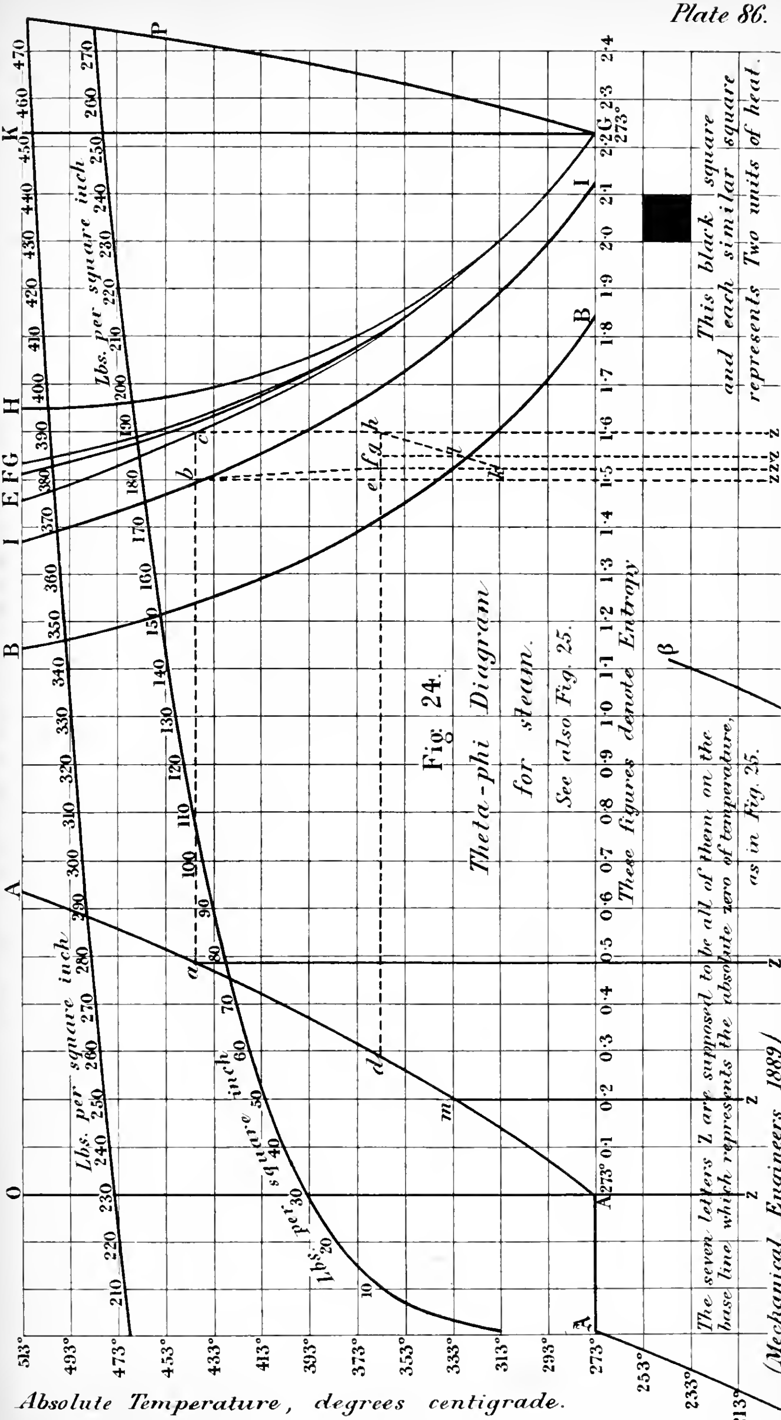
REGNAULT'S STEAM EXPERIMENTS.

Fig. 23. *See Tables 5, 6, and 7.*



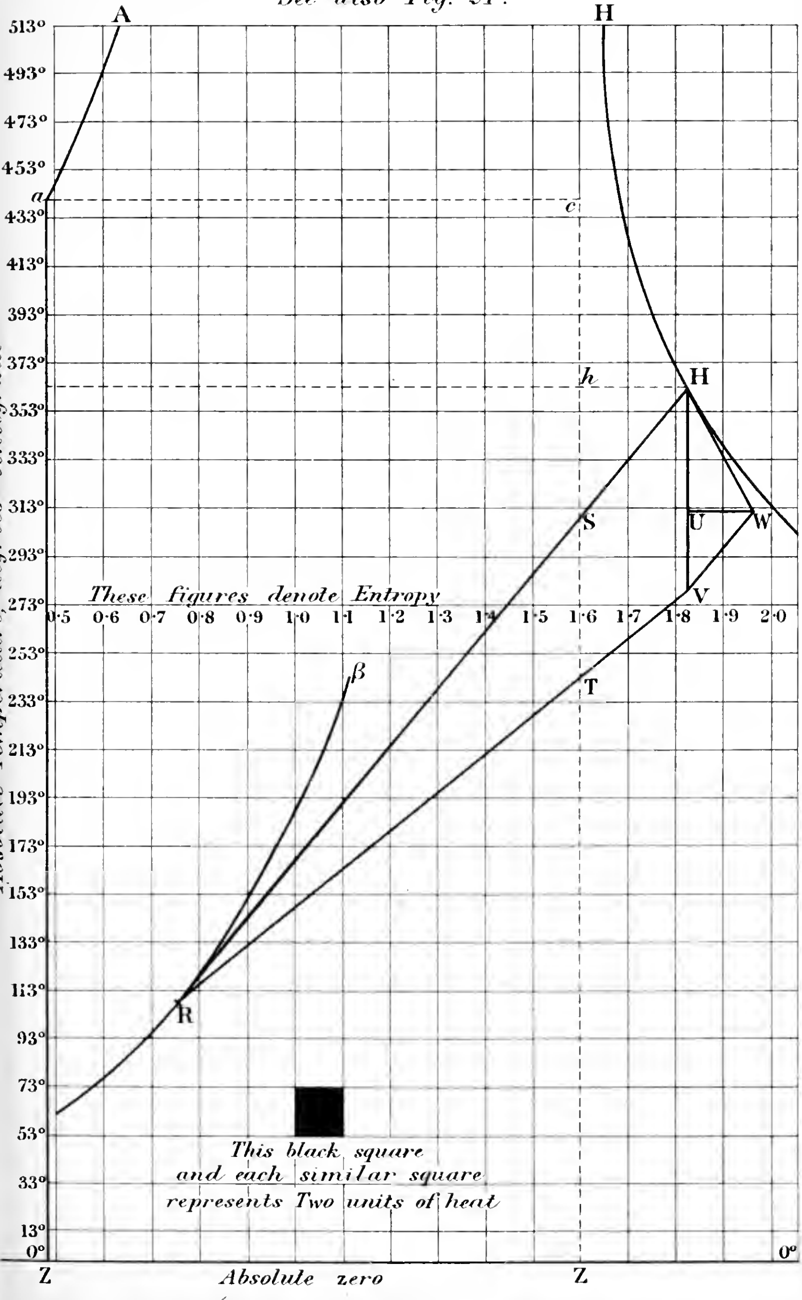
(Mechanical Engineers 1889)

Plate 85.



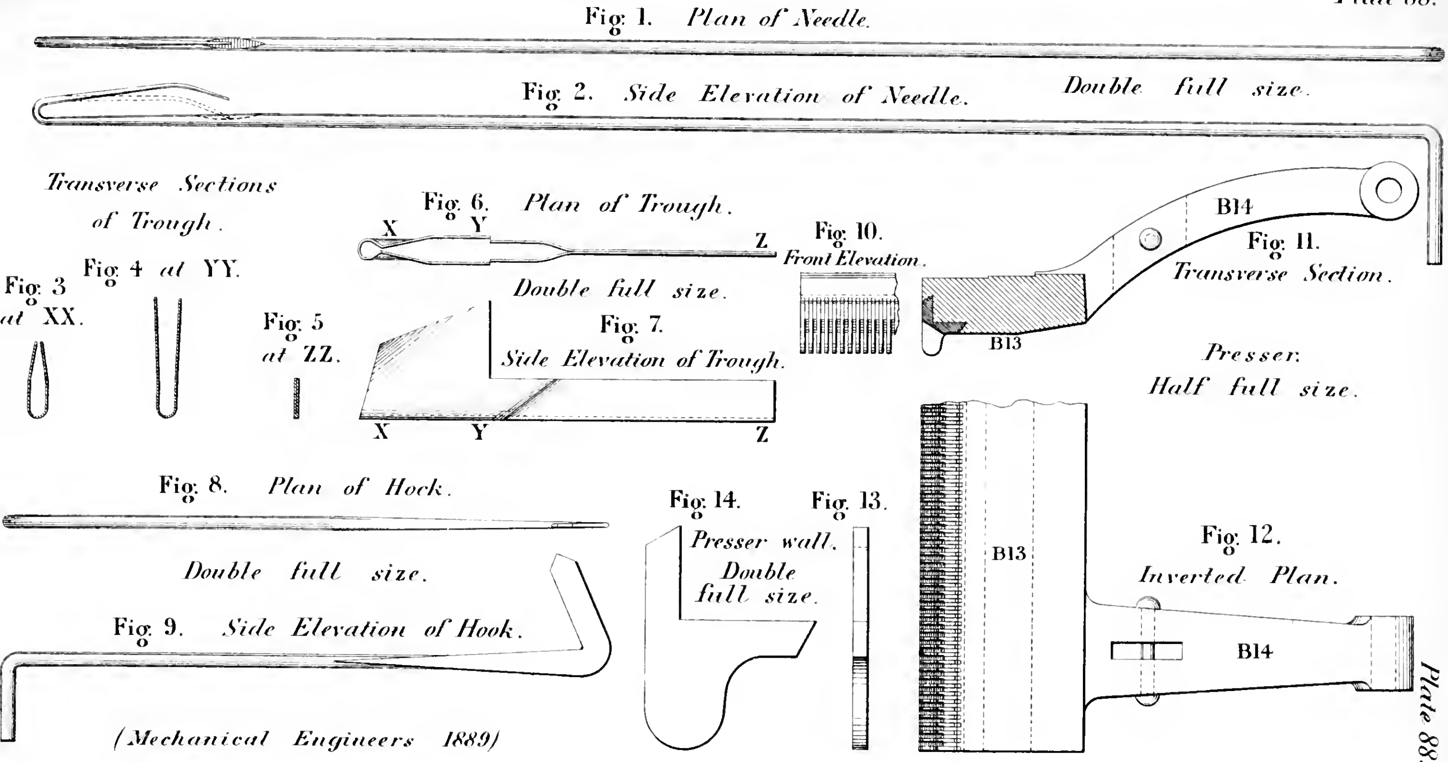
Absolute Temperature, degrees centigrade.

Fig: 25. *Part of Theta-phi Diagram for steam.*
See also Fig. 24.



(Mechanical Engineers 1889)

WARP WEAVING.

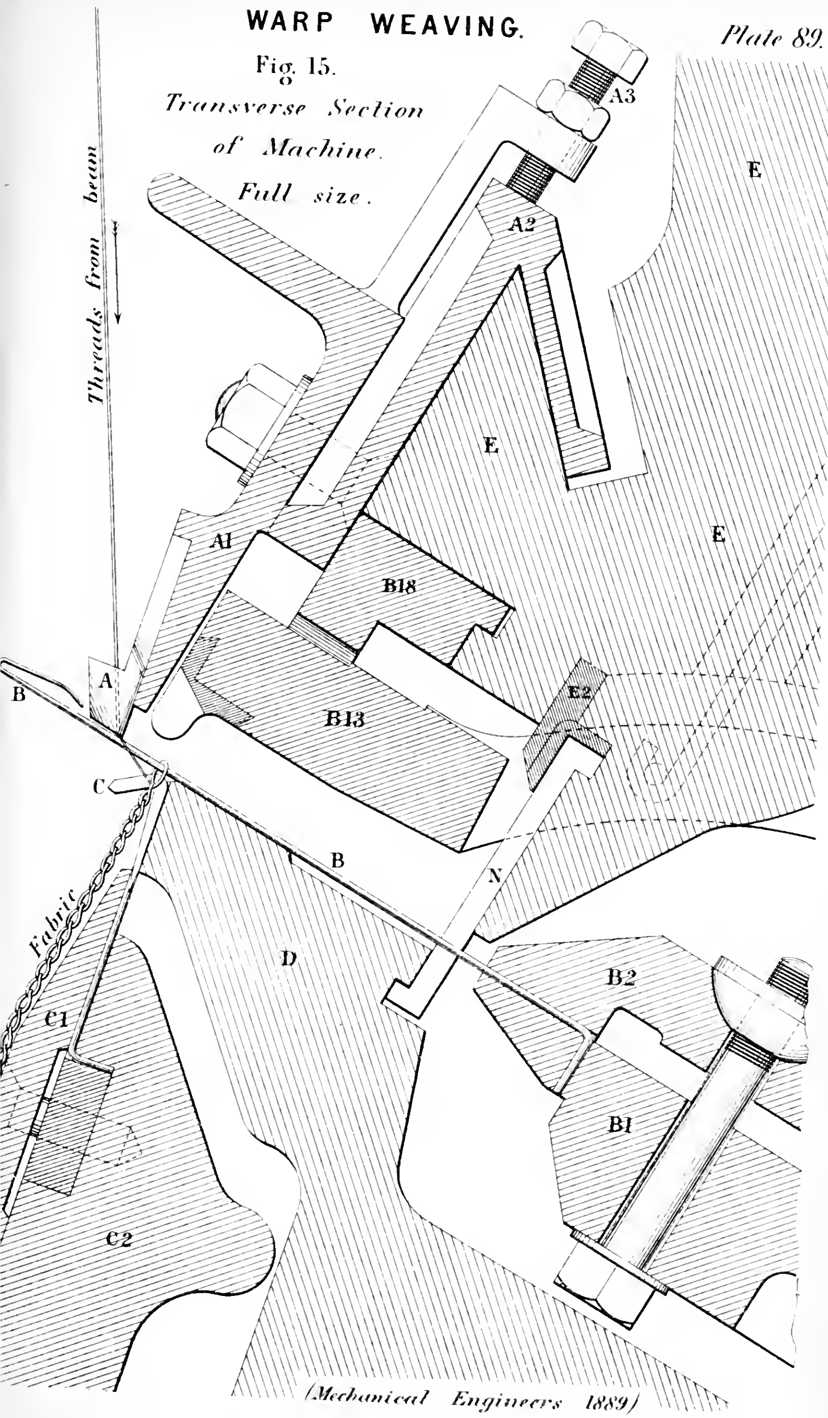


(Mechanical Engineers 1889)

Plate 88.

WARP WEAVING.

Fig. 15.
Transverse Section of Machine. Full size.



(Mechanical Engineers 1889)

Cycle of movements of primary parts.

Scale twice full size.

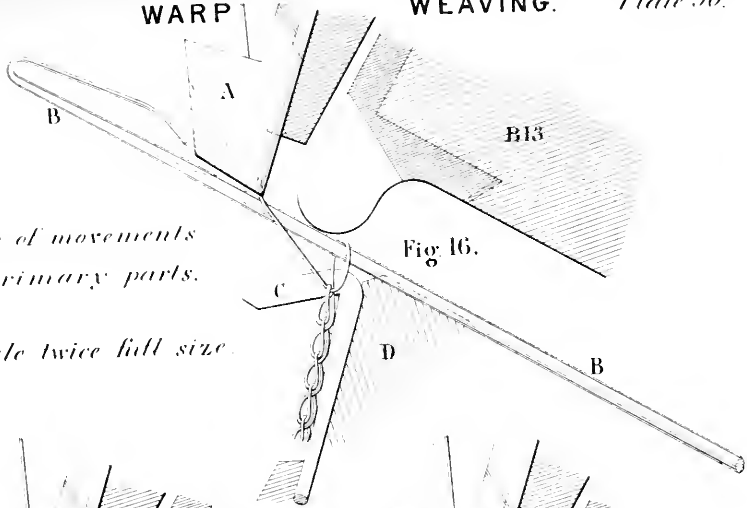


Fig. 16.

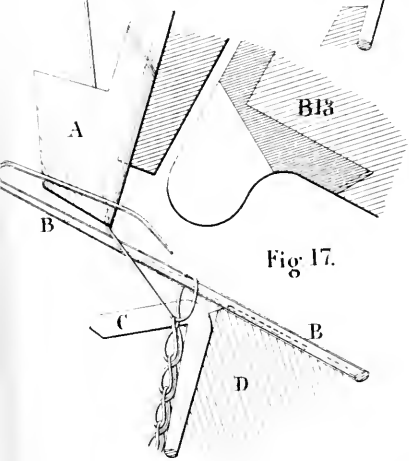


Fig. 17.

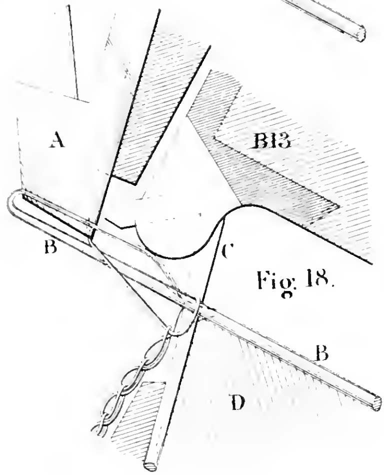


Fig. 18.

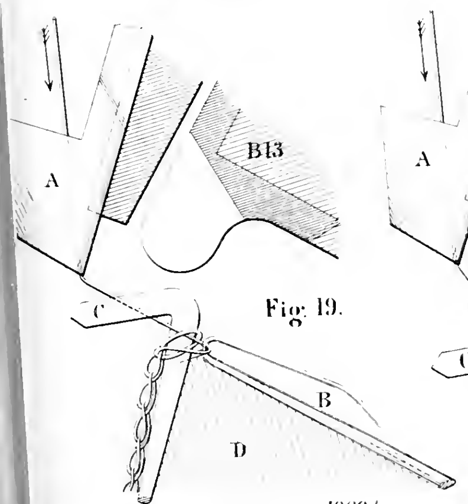


Fig. 19.

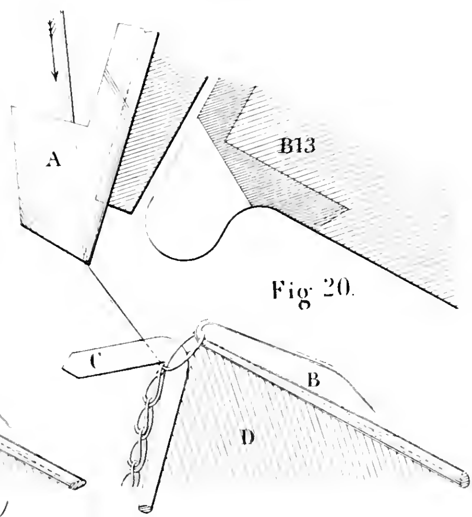


Fig. 20.

(Mechanical Engineers 1889)

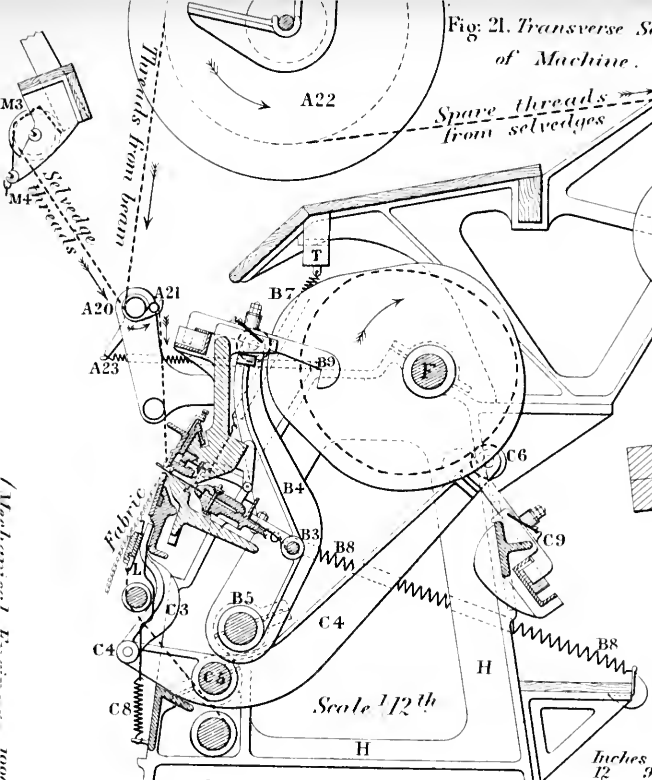


Fig: 21. Transverse Section of Machine.

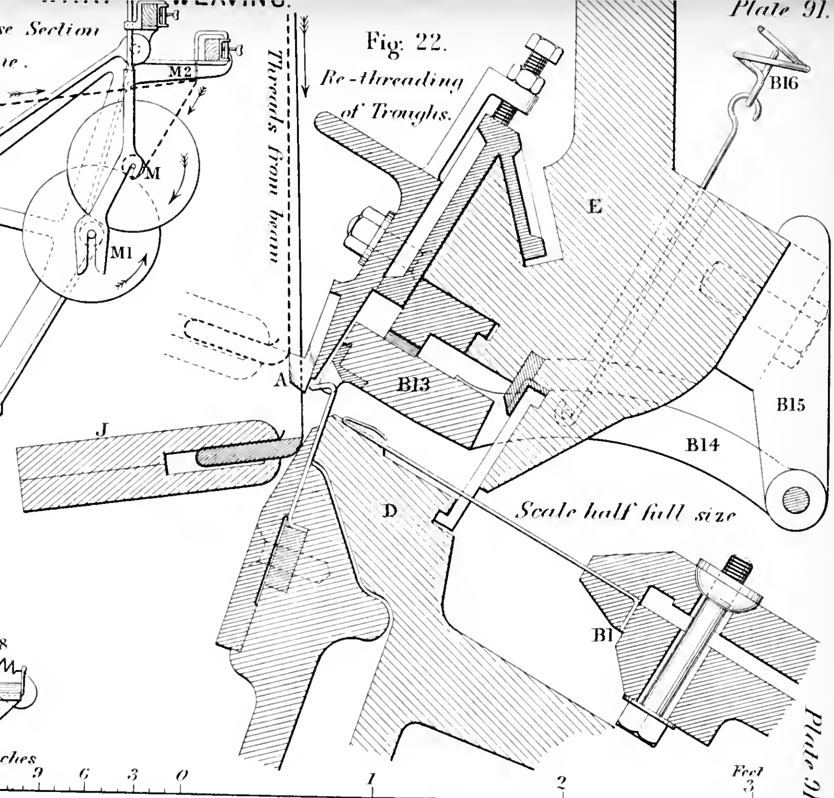
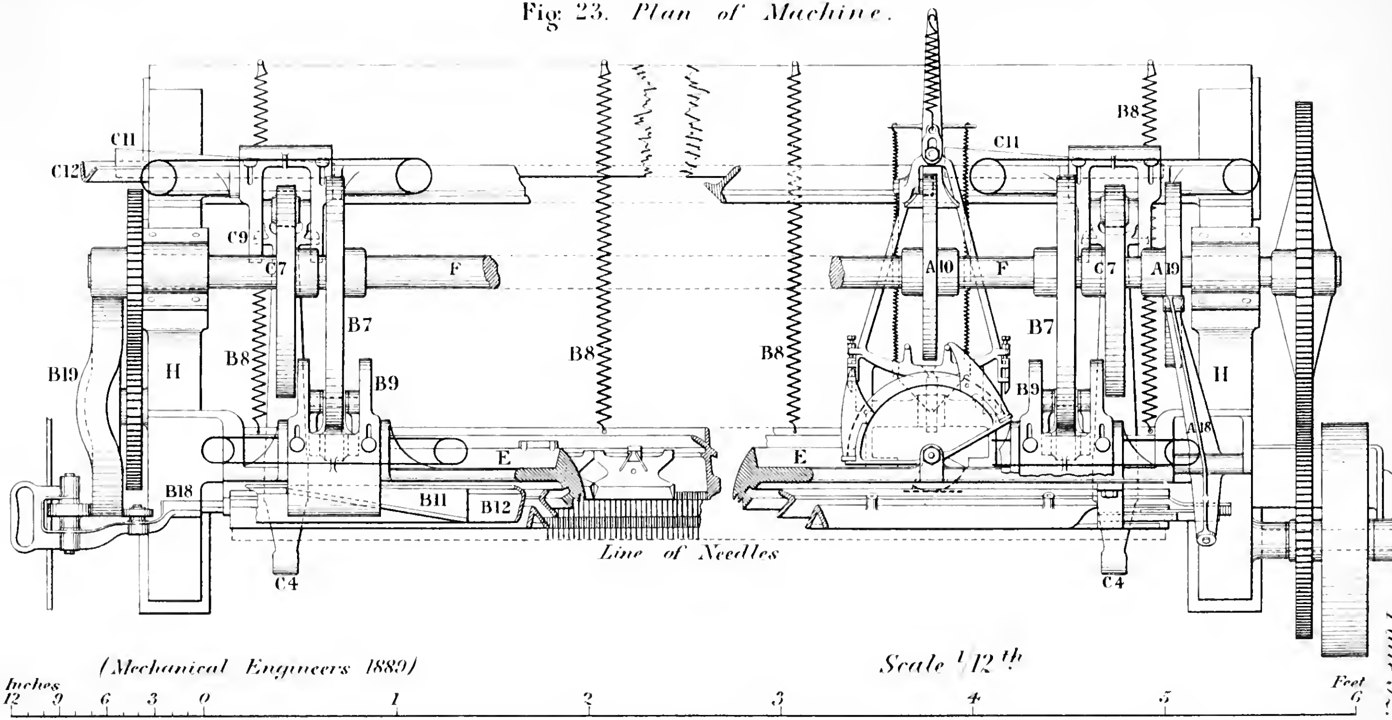


Fig: 22. Re-threading of Troughs.

Plate 91.

WARP WEAVING.

Fig. 23. *Plan of Machine.*



(*Mechanical Engineers 1889*)

Scale 1/12th

Plate 92.

WARP WEAVING.

Mechanism for lateral movement of Troughs.

Fig. 24. *Plan.*

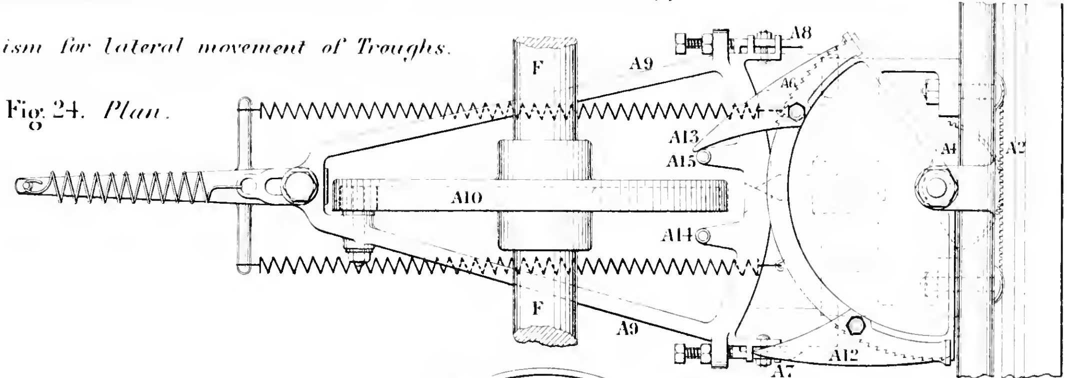
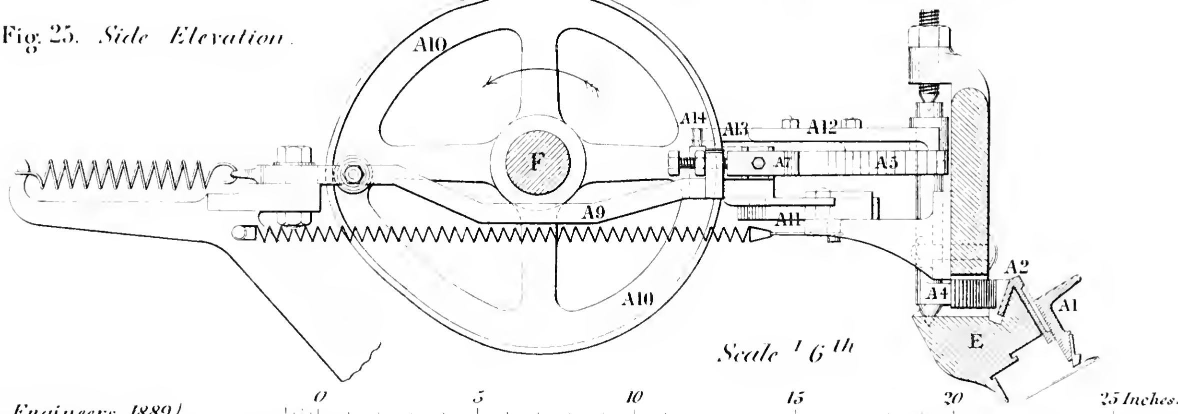


Fig. 25. *Side Elevation.*



(*Mechanical Engineers 1889*)

Plate 93.

WARP WEAVING.

Lock for Trough-Slide-Bar.

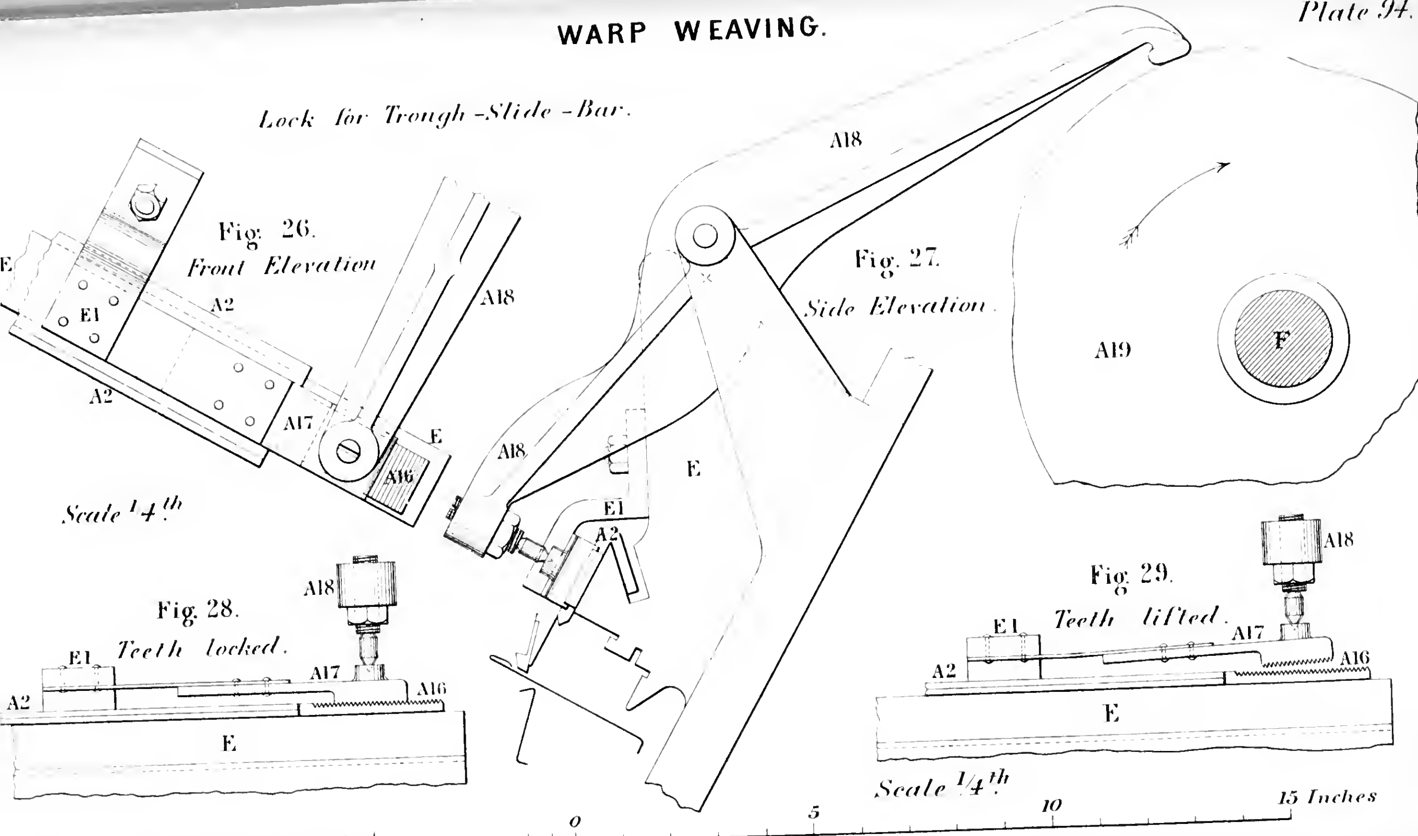


Fig: 26. Front Elevation

Scale 1/4th.

Fig. 27. Side Elevation.

Fig. 28. Teeth locked.

Fig. 29. Teeth lifted.

Scale 1/4th.

(Mechanical Engineers 1889)

Plate 94.

WARP WEAVING.

Stops for Needles and for Hooks.

Fig. 30. End Elevation.

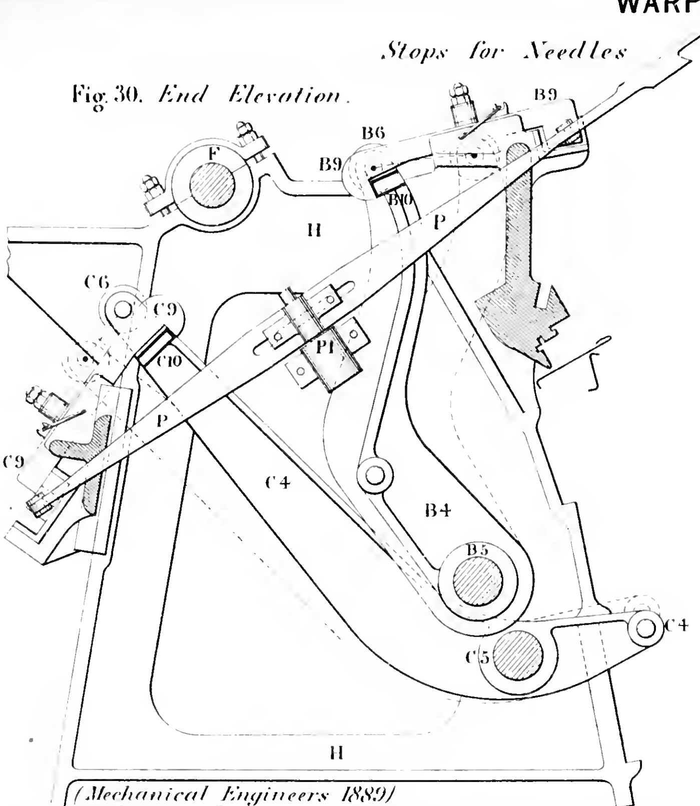


Fig. 31. Plan.

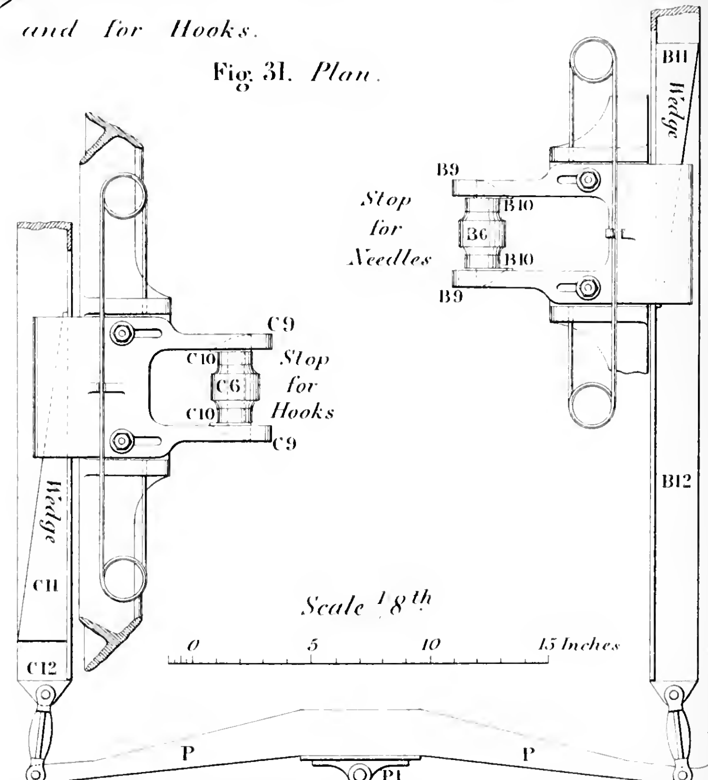


Plate 95.

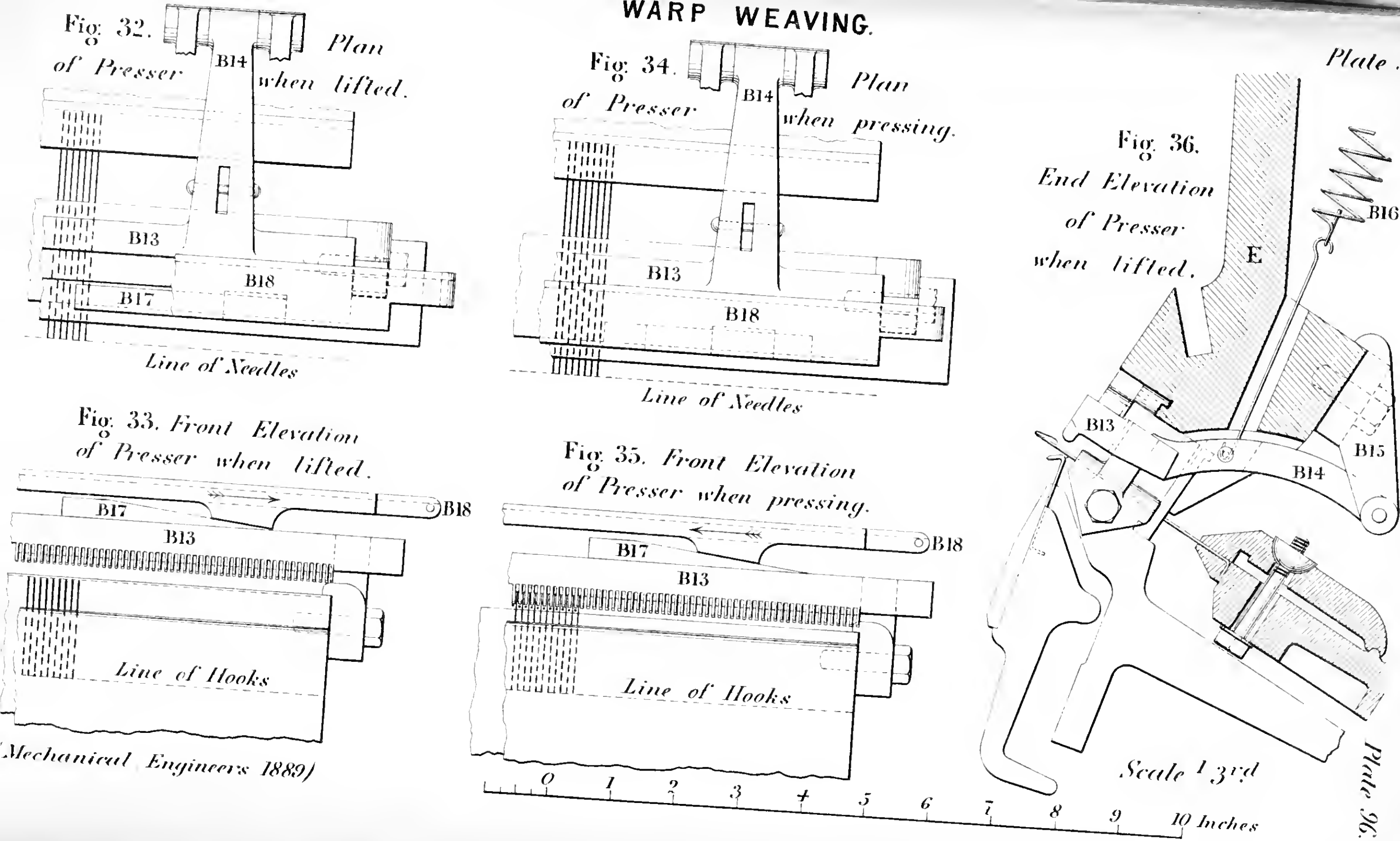


Fig. 32. Plan of Presser when lifted.

Fig. 33. Front Elevation of Presser when lifted.

Fig. 34. Plan of Presser when pressing.

Fig. 35. Front Elevation of Presser when pressing.

Fig. 36. End Elevation of Presser when lifted.

(Mechanical Engineers 1889)

Plate 96.

Fig. 37. Warping Machine.

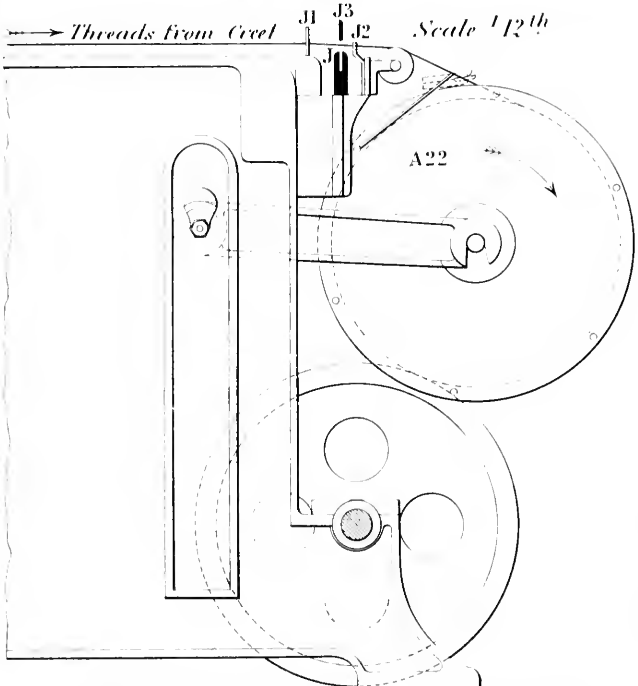
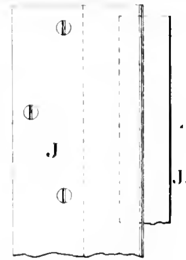


Fig. 38. Plan.



Trapping Bar.

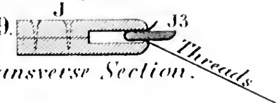


Fig. 39. Transverse Section.

Presser Cam

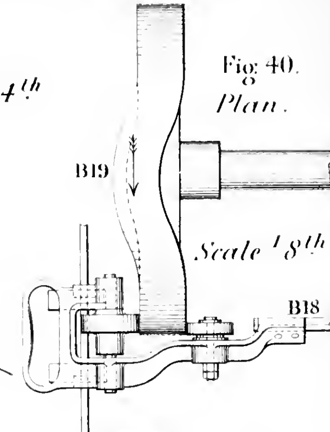


Fig. 40. Plan.

Presser Cam.

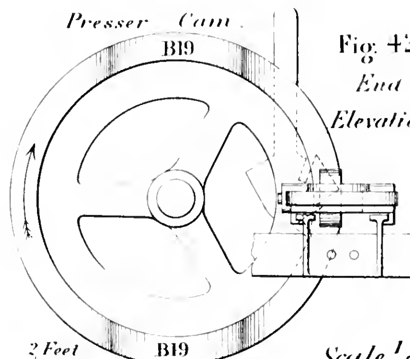


Fig. 42 End Elevation.

Scale 1/8th

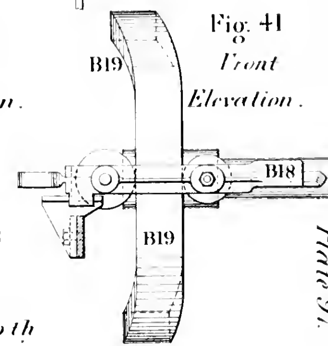


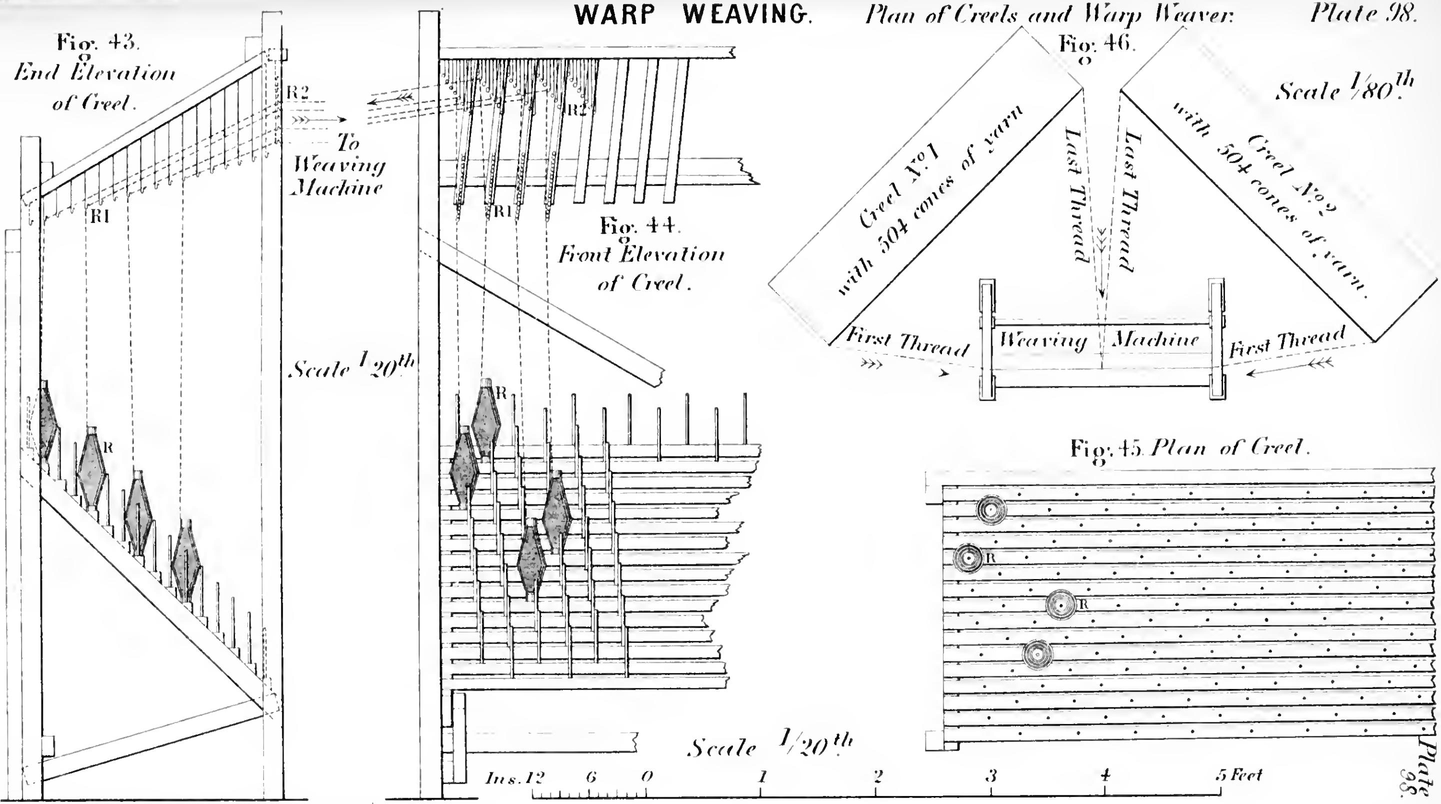
Fig. 41 Front Elevation.

(Mechanical Engineers 1889)

Scale 1/12th

Inches 12 9 6 3 0 1 2 Feet

WARP WEAVING.



(Mechanical Engineers 1889)

Plate 98.

WARP WEAVING.

Tension upon Threads from Creel.

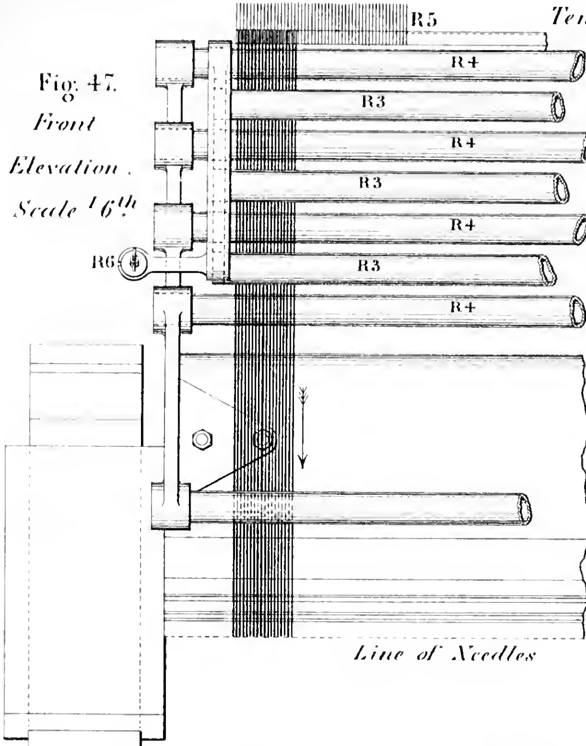


Fig. 47. *Front Elevation. Scale 1/6th.*

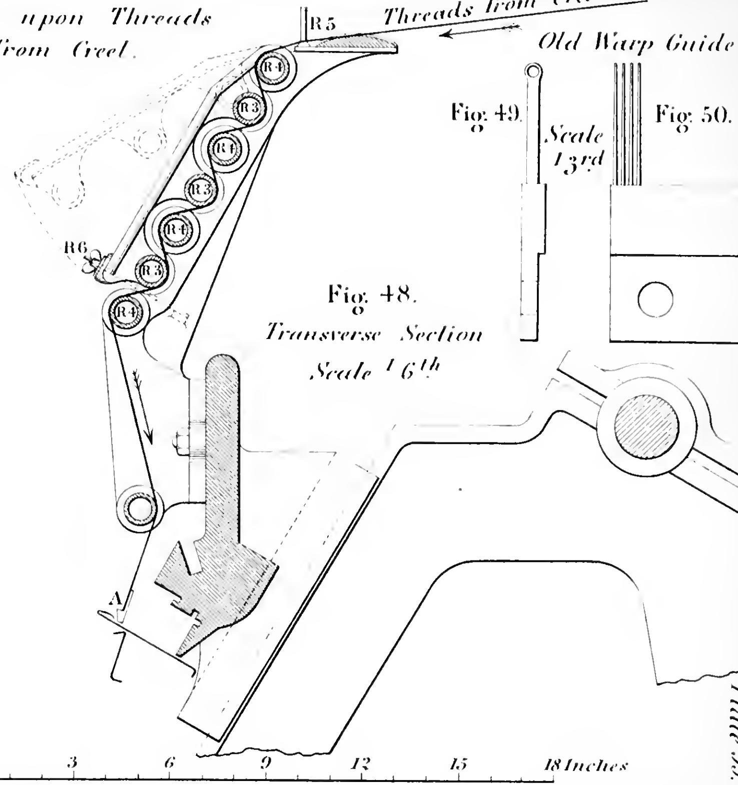


Fig. 48. *Transverse Section Scale 1/6th.*

Old Warp Guide.

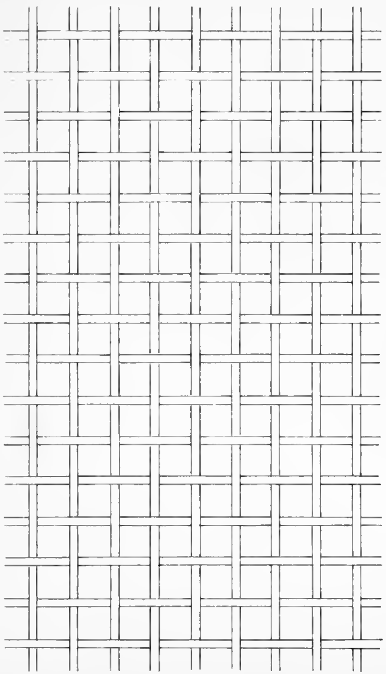
Fig. 49. *Scale 1/3rd.*

Fig. 50.

(Mechanical Engineers 1889) *Scale 1/6th.*

WARP WEAVING.

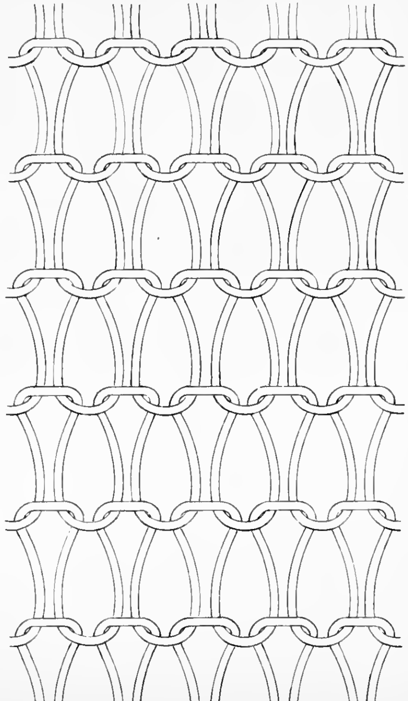
Fig. 51. *Ordinary Weaving, with Warp and Weft.*



(Mechanical Engineers 1889)

Direction of Warp

Fig. 52. *Knitting, with single thread of Weft only.*



Direction of Warp

Fig. 53. *Warp Weaving, with threads of Warp only; one thread to each needle.*

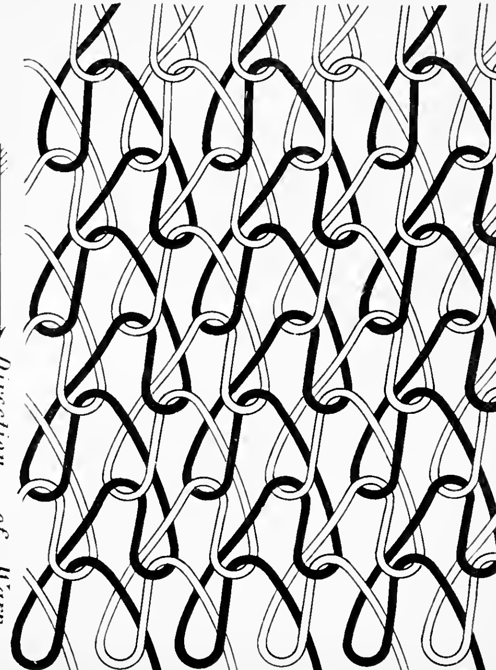


Plate 100.

Barnett Engine 1838.

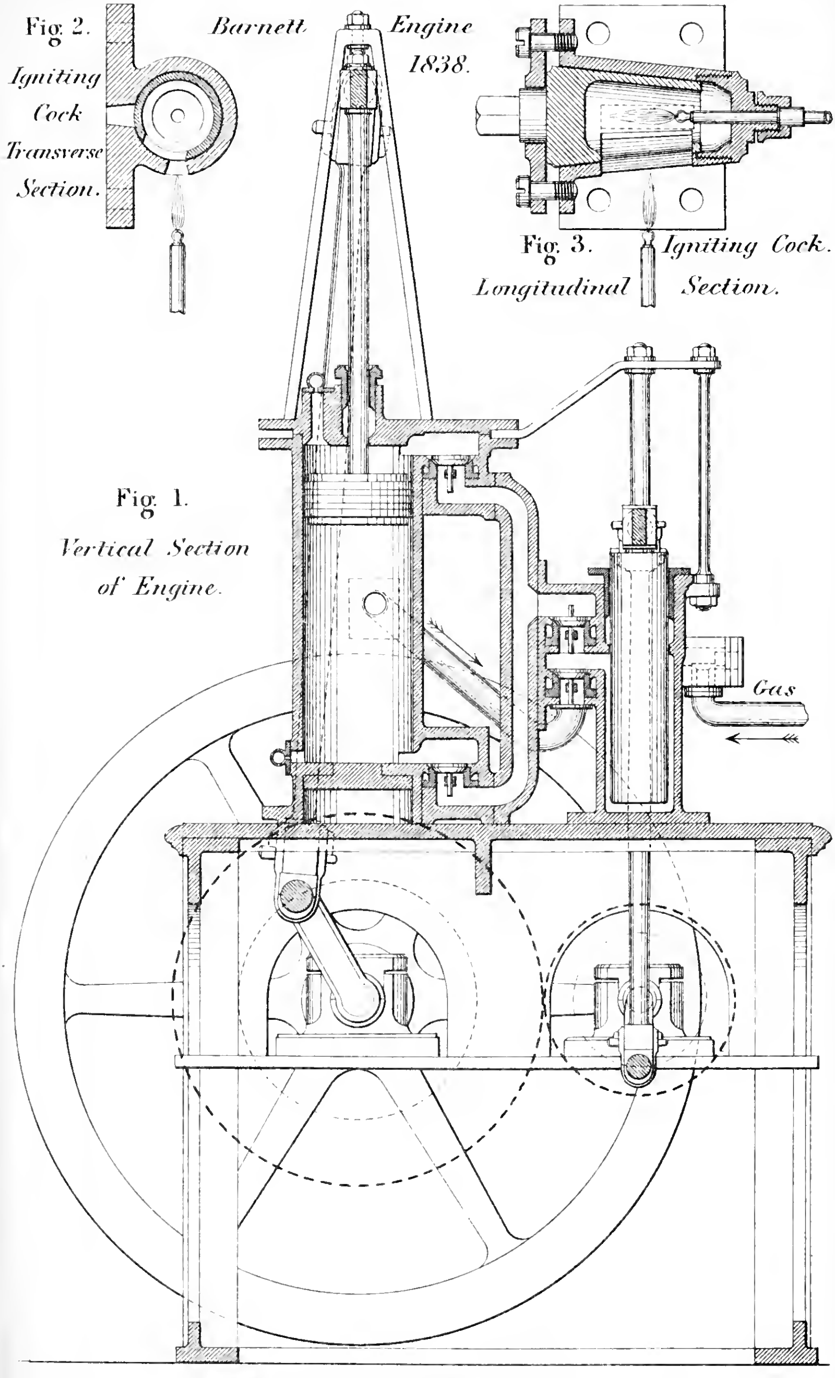


Fig. 2. Igniting Cock Transverse Section.

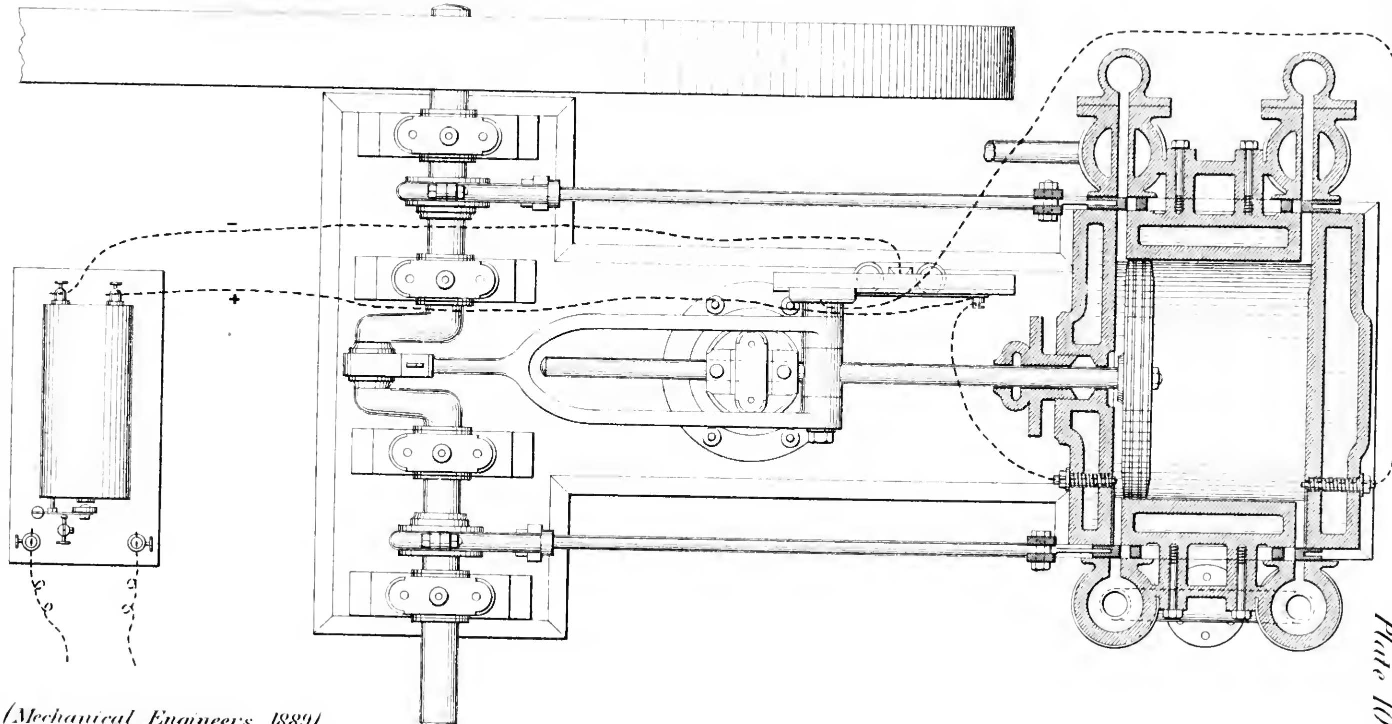
Fig. 3. Igniting Cock. Longitudinal Section.

Fig. 1. Vertical Section of Engine.

(Mechanical Engineers 1889)

GAS ENGINES.

Fig. 4. *Lenoir Engine 1860.*



(Mechanical Engineers 1889)

Plate 102.

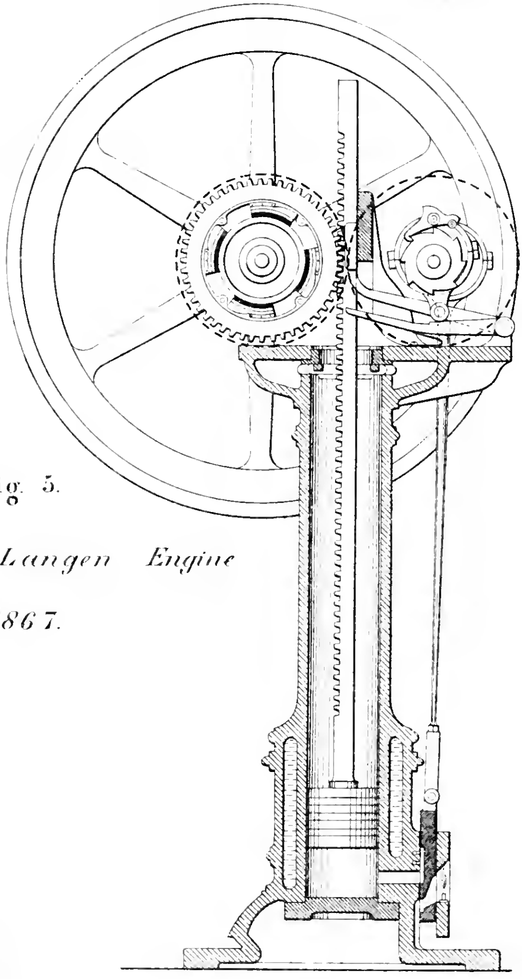


Fig. 5.

Otto and Langen Engine

1867.

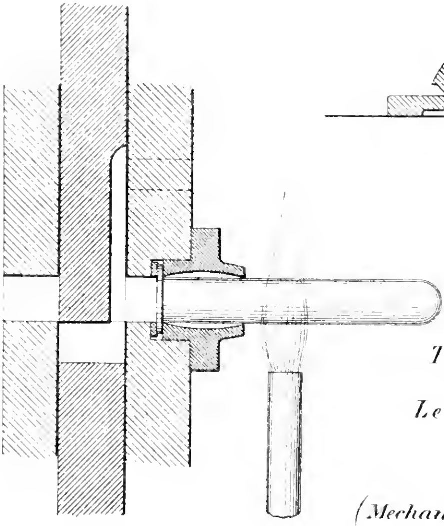


Fig. 6.

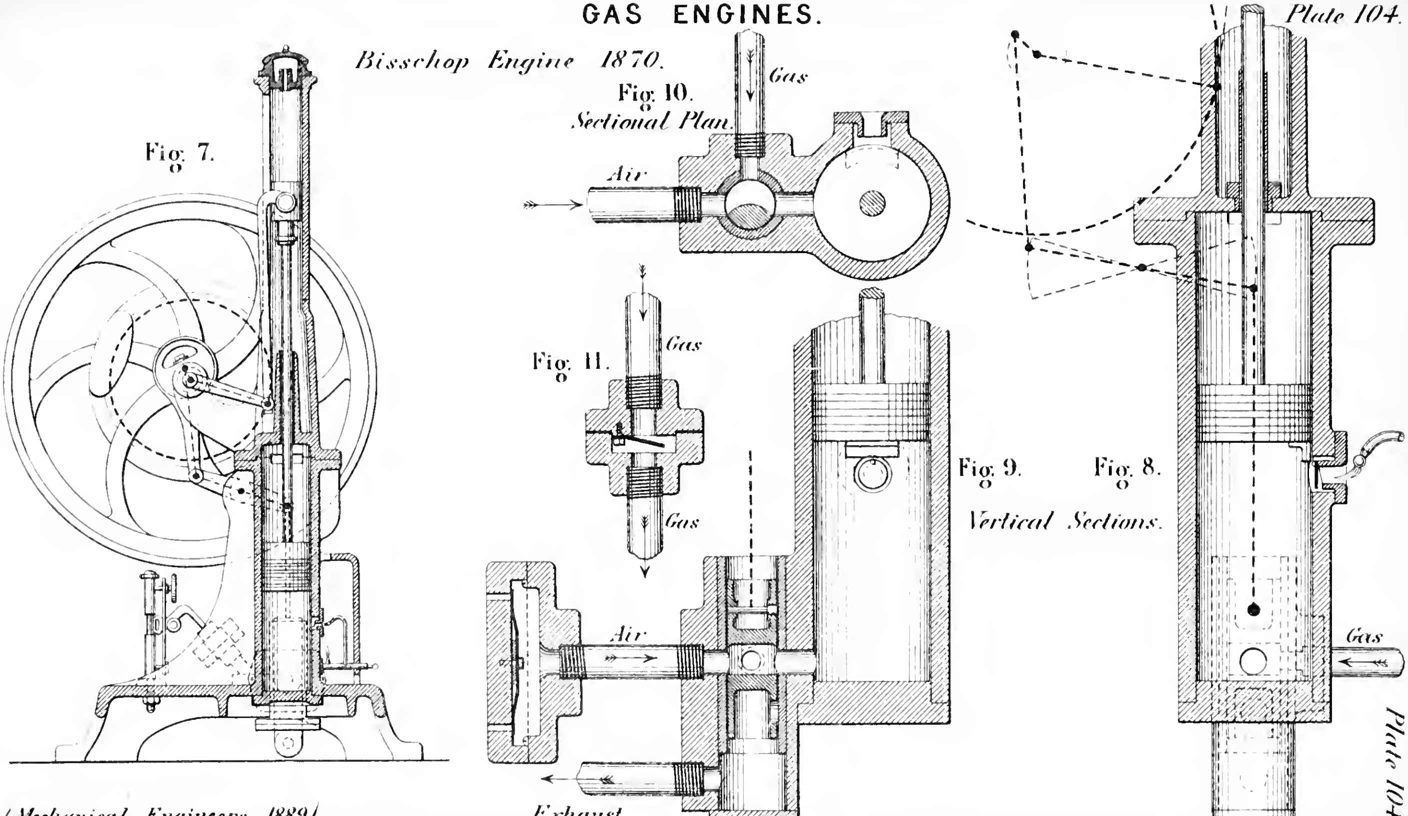
Tube Ignition.

Leo Funck 1879.

(Mechanical Engineers 1889)

GAS ENGINES.

Bisschop Engine 1870.

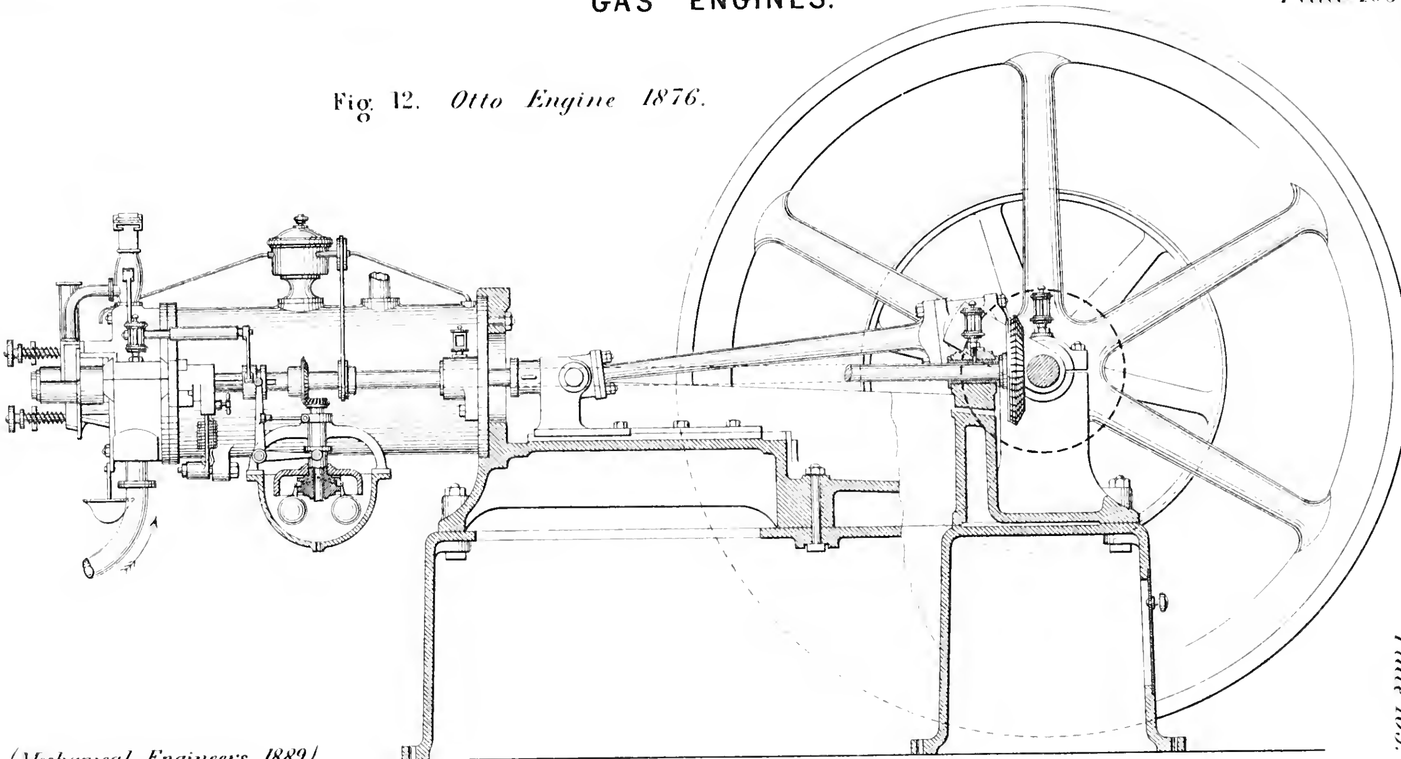


(Mechanical Engineers 1889)

Plate 104.

GAS ENGINES.

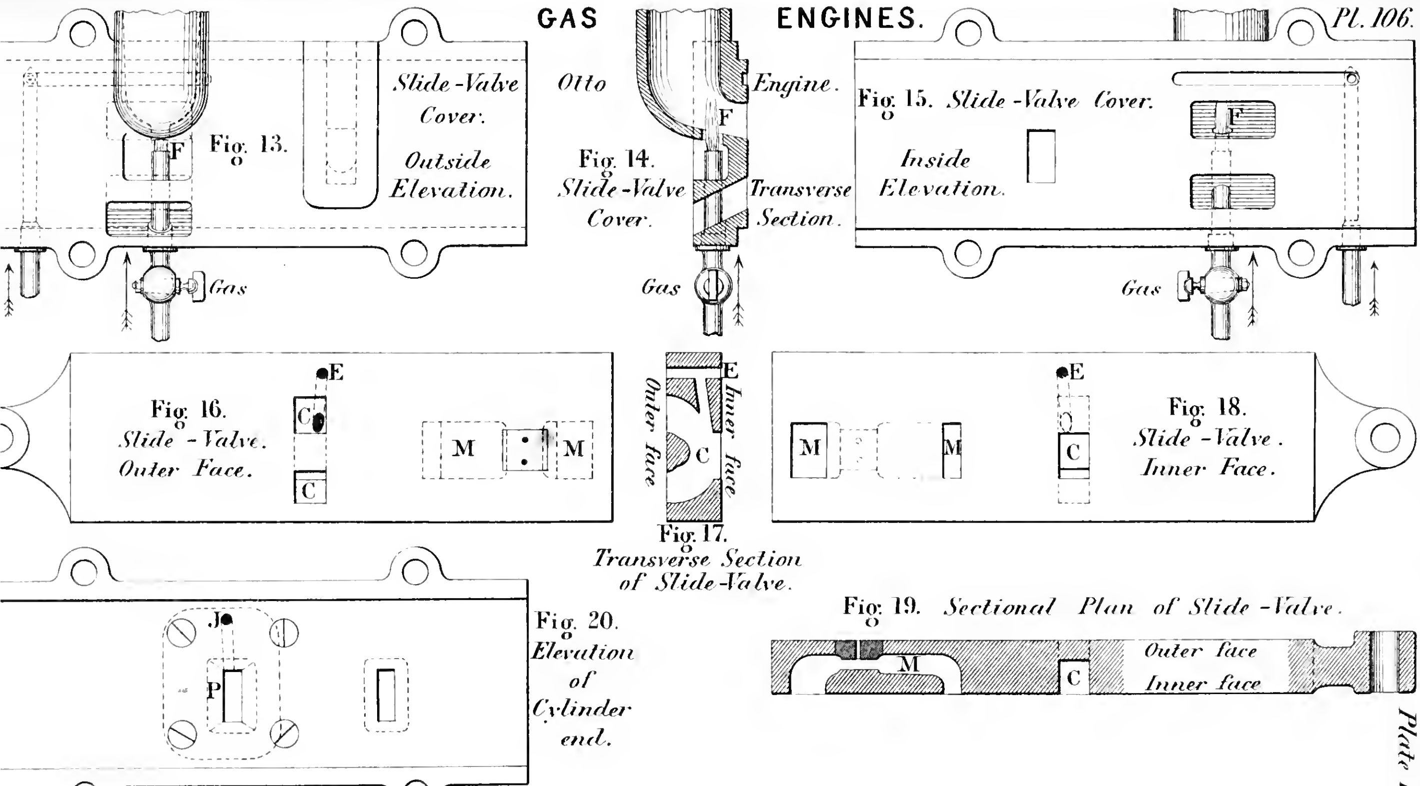
Fig. 12. *Otto Engine 1876.*



(Mechanical Engineers 1889)

Plate 105.

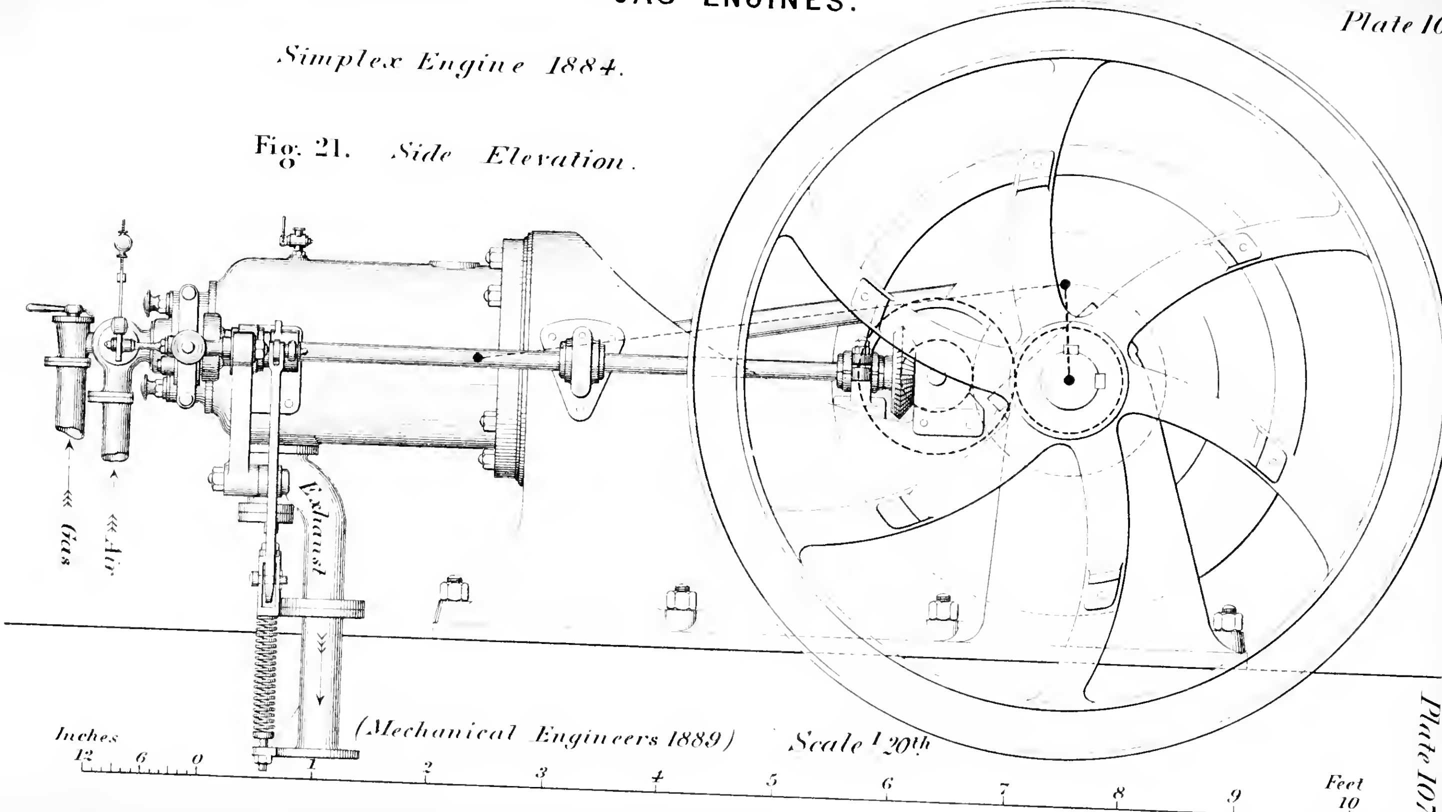
GAS ENGINES.



(Mechanical Engineers 1889)

Simplex Engine 1884.

Fig. 21. Side Elevation.

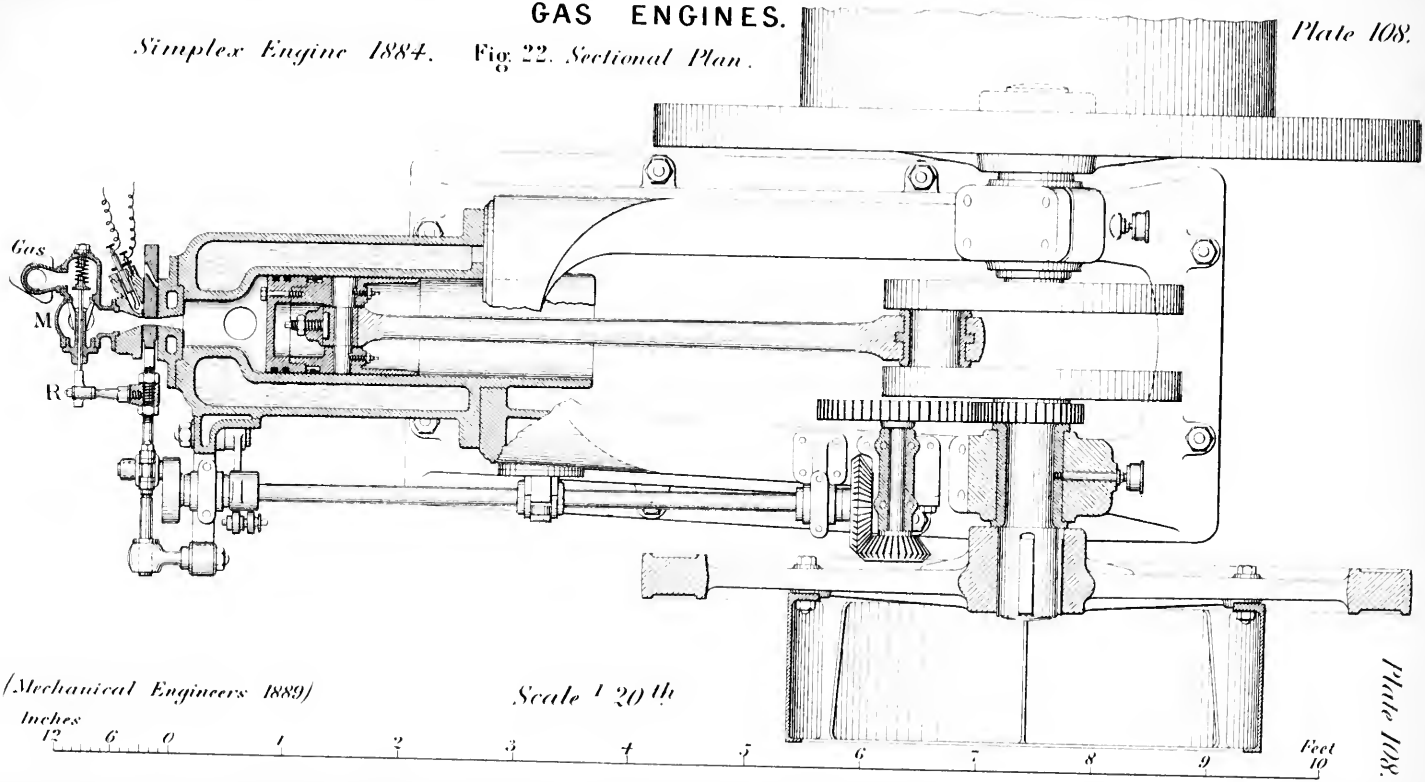


(Mechanical Engineers 1889) Scale 1/20th

Plate 107.

GAS ENGINES.

Simplex Engine 1884. Fig. 22. *Sectional Plan.*



(Mechanical Engineers 1889)

Scale 1/20th

Plate 108.

Simplex Engine 1884.

Fig. 23.

Back Elevation.

Scale 1/20th.

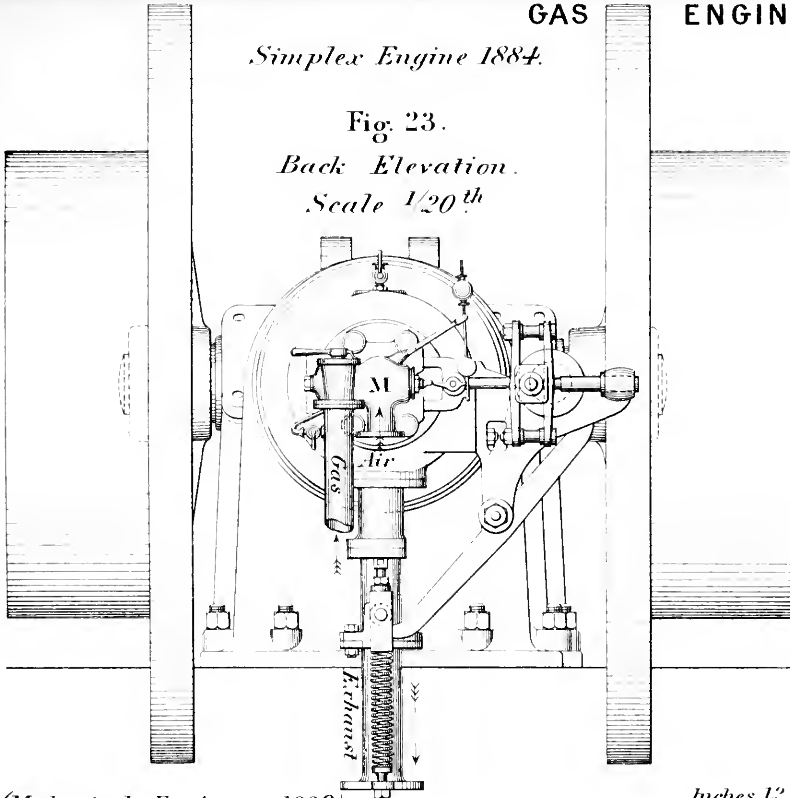
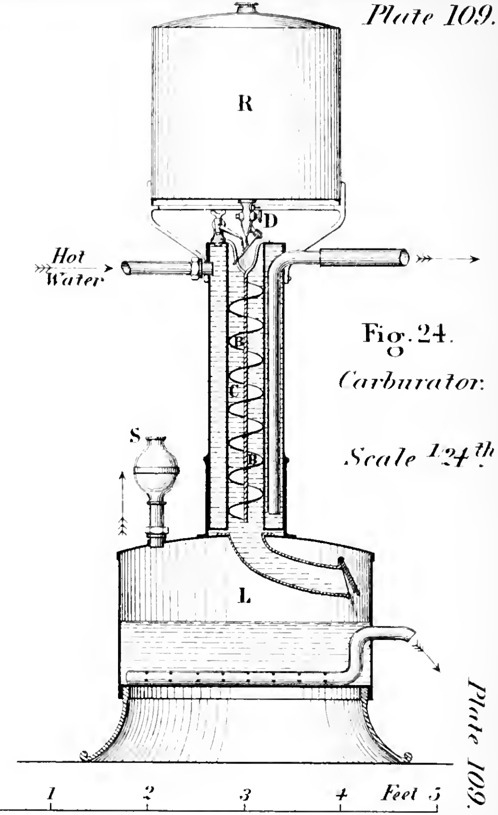


Fig. 24.

Carburator.

Scale 1/24th.



(Mechanical Engineers 1889)

Plate 109.

Simplex Engine 1884.

Pendulum Governor.

Fig. 25.

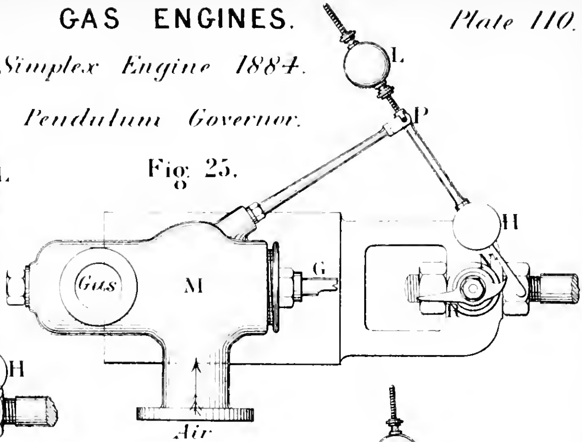


Fig. 27.
Misfire.

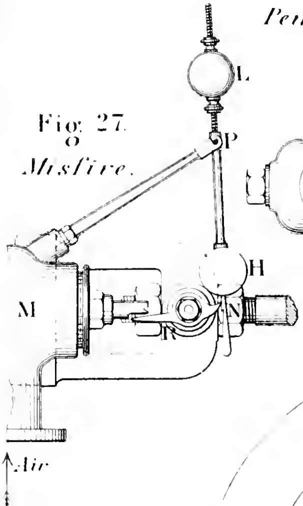


Fig. 26.
Back Elevation.

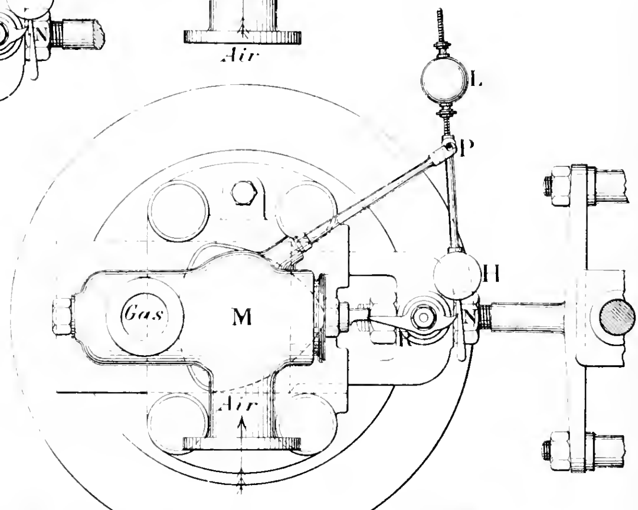
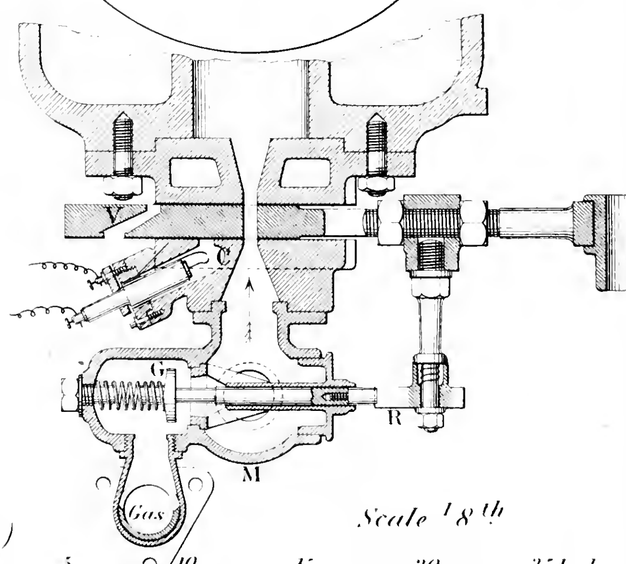


Fig. 28.
Sectional Plan.



(Mechanical Engineers 1889)

Scale 1/8th

0 5 10 15 20 25 *Inches*

GAS ENGINES.

Air Governor.

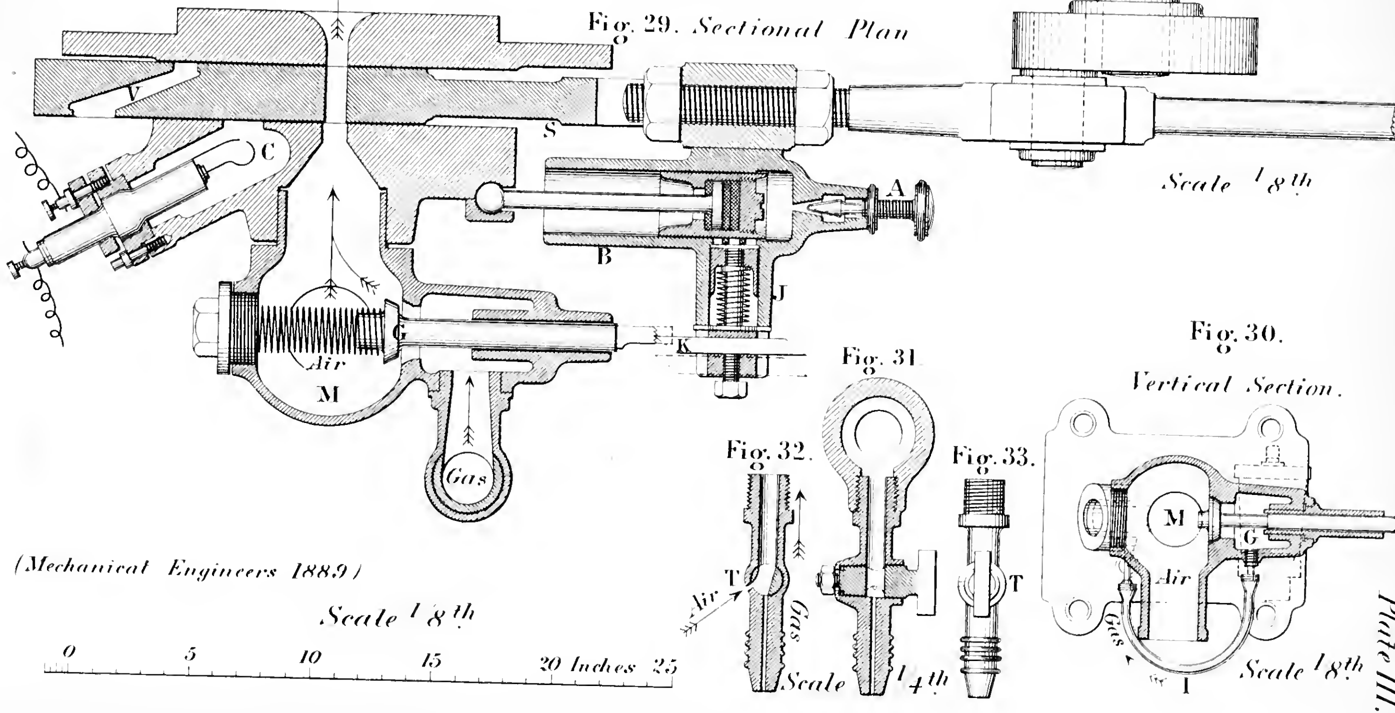


Plate III.

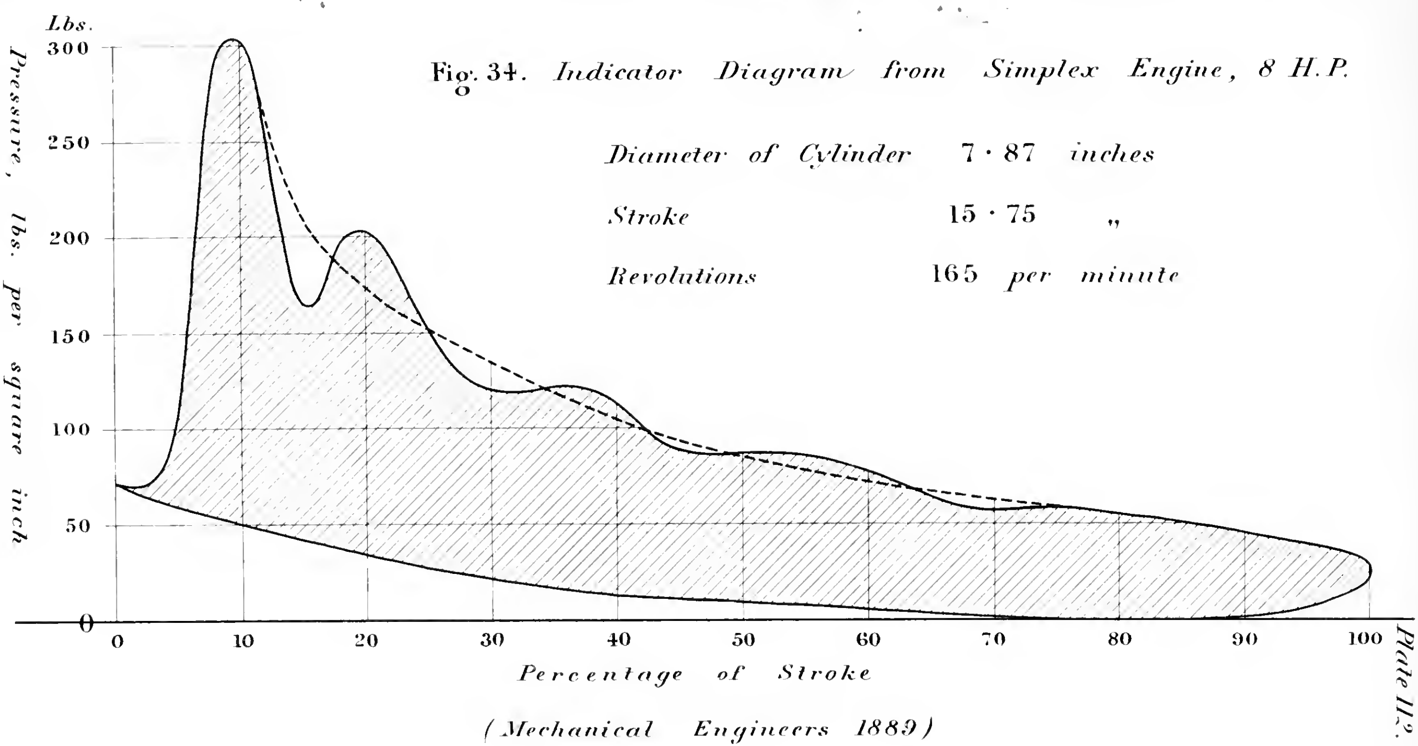
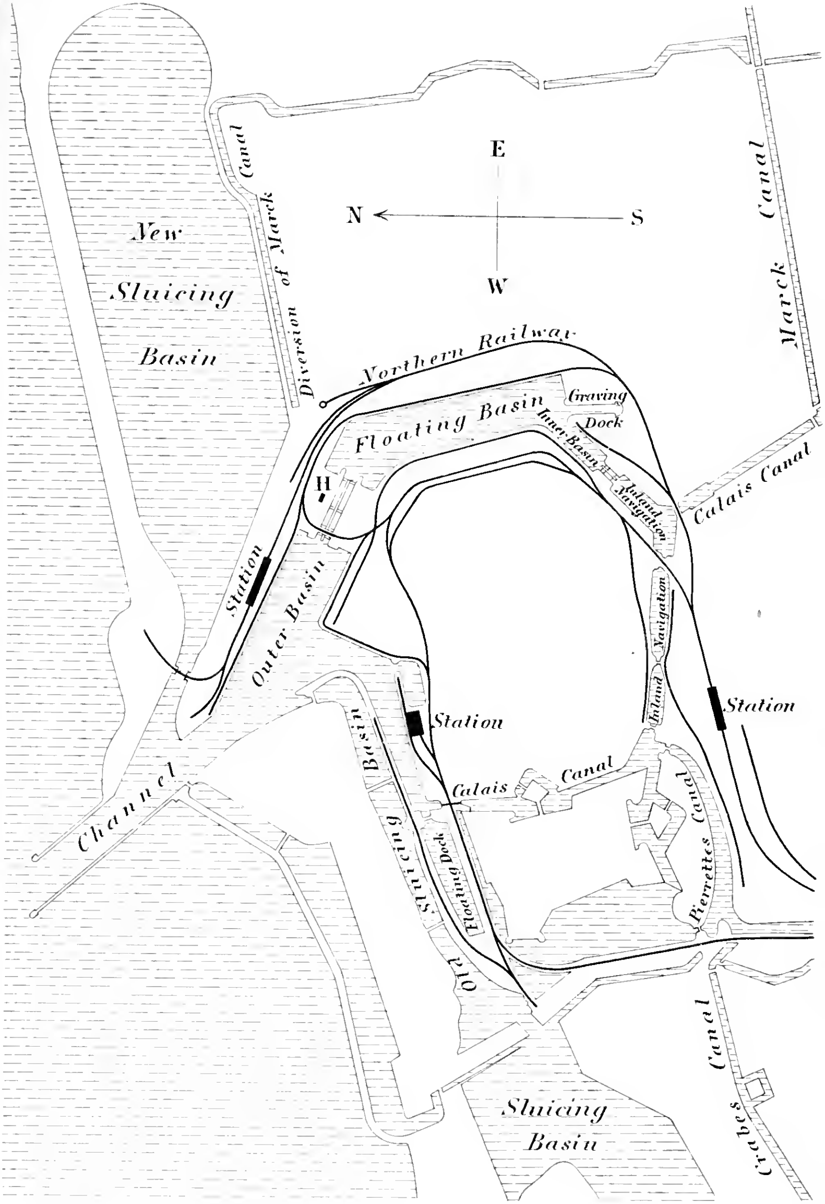


Fig. 34. Indicator Diagram from Simplex Engine, 8 H.P.
Diameter of Cylinder 7·87 inches
Stroke 15·75 „
Revolutions 165 per minute
Lbs.
300
250
200
150
100
50
0
Pressure, lbs. per square inch
0
10
20
30
40
50
60
70
80
90
100
Percentage of Stroke
(Mechanical Engineers 1889)
Plate 112.

CALAIS HARBOUR WORKS.

Plate 113.



Scale 2 3/4 inches per mile.

0 1/4 1/2 3/4 1 1 1/4 Mile 1 1/2

(Mechanical Engineers 1889)

Institution of Mechanical Engineers.

BINDING OF PROCEEDINGS.

In compliance with a desire expressed by some of the Members that there should be a convenient arrangement for the uniform binding of the Institution Proceedings, the Council have selected a suitable dark cloth Cover with gilt lettering for the yearly volumes; and have arranged that any Member sending his numbers of the Proceedings direct to the binders (not to the Institution) can have them so bound in their yearly volumes at the cost of fifteen pence per volume, exclusive of carriage or postage to and fro.

Members wishing to avail themselves of this arrangement are requested to forward their several parts of the Proceedings (carriage prepaid) *direct to the binders*, Messrs. William Clowes & Sons, Duke Street, Stamford Street, London, S.E.; and to state the address to which the bound volumes are to be returned.

Any Member, giving due notice to the Secretary before the issue of the first part of any year's volume, may have the several parts of the Proceedings for that and subsequent years retained for him at the Institution, and forwarded annually in a single volume bound as above at his expense.

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1889.

The Autumn Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, 30th October 1889, at Half-past Seven o'clock p.m.; Charles Cochrane, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that, in connection with the recent Summer Meeting in Paris, the Council had nominated as an Honorary Life Member of the Institution M. Gustave Eiffel, President of the Société des Ingénieurs Civils, in acknowledgment of all that had been done by the Society under his auspices for ensuring the success of the Paris Meeting, and also in recognition of his eminent position in the engineering profession, and of the world-wide celebrity attaching to his works.

The President announced that the Council had resolved, in connection with the Summer Meeting in Paris, that a Recording Barometer, bearing a suitable inscription, be presented by the Institution to Mr. Henry Chapman, in testimony of their grateful appreciation of his renewed kindness in again giving his valued aid and experience as Honorary Secretary for the recent third successful Summer Meeting of the Institution in Paris, having obligingly acted in the same capacity for the two previous Paris Meetings in 1867 and 1878.

The Council had further resolved that the cordial Thanks of the Institution, engrossed upon vellum and framed, be presented to M. Henri Vaslin, in recognition of the energetic and obliging manner in which he had shared in maturing and carrying out the various arrangements for the Paris Meeting, whereby the success of the Meeting had been ensured, and the enjoyment of the Members enhanced.

The Council had also presented, on behalf of the Institution, a Kodak Camera to M. Armand de Dax, the Agent General of the Société des Ingénieurs Civils, as a memento of his obliging exertions in that capacity for the advantage of the Members at the Paris Meeting.

The President announced that the Ballot Lists for the election of New Members, Associates, and Graduates, had been opened by a committee of the Council, and that the following forty candidates were found to be duly elected :—

MEMBERS.

Alexander Atkinson,	Kashmir.
Robert Bruce,	London.
William Newby Colam,	Edinburgh.
Frederick James Cribb,	Gainsborough.
James Robert Dalgarno,	Aberdeen.
George Henry Hawkins Emett,	Dewsbury.
George Wilson Heath,	London.
George Herbert Hodgson,	Bradford.
Thomas Harry Houghton,	London.
Charles Lafayette Hunter,	Cardiff.
William Jackson,	Aberdeen.
Reginald William James,	London.
George Jessop,	Leicester.
Frank Eugene Kirby,	Detroit, U.S.
Henry Meredith Leaf,	London.
William Snell Tandy Magee,	Melbourne.
David John Morgan,	Cardiff.
Evan Henry Parry,	Swansea.

Enrico Riva, ...	Florence.
Nisbet Sinclair, ...	Glasgow.
John Dann Smelt, ...	London.
Dare Arthur Stuart-Hartland, .	Calcutta.
James Donnithorne Thomas, . .	London.
Robert McNidar Thomson, . .	Kobe, Japan.
William Walton Williams, Jun., .	Buenos Aires.
Alfred Fernandez Yarrow, . .	London.
David Young, ...	London.

ASSOCIATES.

Frederick George Castle, . .	London.
John George Chamberlain, . .	Tipton.

GRADUATES.

John Ashford, ...	Birmingham.
Arthur Selwyn Brown, . . .	Sydney.
John Carlos Calastremé, . . .	Glasgow.
Gilbert Harwood Harrison, Lieut. R.E.,	Woolwich.
Robert Francis Hayward, . .	Chelmsford.
Arthur Fayrer Hosken, . . .	Brighton.
Geoffrey Howard, ...	Bedford.
Frank Theodore Marshall, . .	Newcastle-on-Tyne.
Harold Lincoln Tangye, . . .	Birmingham.
Gwilym Alexander Treharne, . .	Pontypridd.
Howard Theophilus Wright, . .	London.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and the list of those retiring was as follows:—

PRESIDENT.

Charles Cochrane, ...	Stourbridge.

VICE-PRESIDENTS.

Daniel Adamson, ...	Manchester.
Sir James Ramsden, ...	Barrow-in-Furness.

MEMBERS OF COUNCIL.

Sir Douglas Galton, K.C.B., D.C.L., F.R.S.,	London.
John Hopkinson, Jun., D.Sc., F.R.S.,	London.
Samuel W. Johnson,	Derby.
William Laird,	Birkenhead.
Edward P. Martin,	Dowlais.

Of these, the President regretted that he found himself unable from various considerations to accept nomination for a second year of office. The two Vice-Presidents and the five Members of Council all offered themselves for re-election.

The following nominations had also been made by the Council for the election at the Annual General Meeting :—

PRESIDENT.

Joseph Tomlinson,	London.

MEMBERS OF COUNCIL.

Election as Member.		
1859.	R. Price-Williams,	London.
1873.	Henry Davey,	London.
1873.	William Henry Maw,	London.
1876.	Henry Shield,	Liverpool.
1888.	William Henry White, F.R.S.,	London.

The President reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

No other names were added.

The President announced that the foregoing names would accordingly constitute the nomination list for the election of officers at the Annual General Meeting.

The President gave notice, on behalf of the Council, of motions to be proposed at the ensuing Annual General Meeting for the three following new By-laws :—

New By-law to follow immediately after the existing By-law 11 :—" Any Member or Associate whose subscription is not in arrear may at any time compound for his subscription for the current and

all future years by the payment of Fifty Pounds. All compositions shall be deemed to be capital moneys of the Institution."

New By-law to follow immediately after the existing By-law 6:—"The abbreviated distinctive Titles for indicating the connection with the Institution of Members, Graduates, Associates, or Honorary Life Members thereof, shall be the following:—for Members, M. I. Mech. E.; for Graduates, G. I. Mech. E.; for Associates, A. I. Mech. E.; for Honorary Life Members, Hon. M. I. Mech. E."

New By-law to follow also after the existing By-law 6:—"Subject to such regulations as the Council may from time to time prescribe, any Member, Graduate, or Associate may upon application to the Secretary obtain a Certificate of his membership or other connection with the Institution. Every such certificate shall remain the property of, and shall on demand be returned to, the Institution."

The President announced that the Council had had under their consideration the question of the Taxation of Machinery, to which they invited the attention of the Members of this Institution, to whom the subject must be of more or less direct importance. For dealing with this matter the National Society for the Exemption of Machinery from Rating had recently been formed; and the Council were glad to take this earliest opportunity of giving expression in their corporate capacity to their cordial sympathy with the object of the Society. Being confirmed by their Honorary Solicitor's advice in the opinion that the funds of the Institution were not available for forwarding this object, the Council urged upon all the Members, who might wish to show their individual interest therein, that they should communicate at once with the Society, from whose office at 22 Buckingham Street, Adelphi, London, W.C., papers and full information would be supplied.

Mr. Benjamin A. Dobson, Member of Council, gave notice to propose the following resolution at the ensuing Annual General Meeting:—"That the President be requested to convey to the

National Society for the Exemption of Machinery from Rating the hearty sympathy of this Meeting with the object of the Society."

The following Paper was then read and discussed:—

On the results of Blast-Furnace Practice with Lime instead of Limestone as Flux; by the PRESIDENT.

During the Discussion of the President's Paper the chair was occupied by JOSEPH TOMLINSON, Esq., Vice-President.

At Half-past Nine o'clock the Meeting was adjourned to the following evening. The attendance was 67 Members and 34 Visitors.

The ADJOURNED MEETING was held at the Institution of Civil Engineers, London, on Thursday, 31st October 1889, at Half-past Seven o'clock p.m.; CHARLES COCHRANE, Esq., President, in the chair.

The following Papers were read and discussed:—

Description of a Rotary Machine for making Block-bottomed Paper Bags; by Mr. JOB DUERDEN, of Burnley. Communicated through Mr. HENRY CHAPMAN, of London.

Further Experiments on Condensation and Re-evaporation of Steam in a Jacketed Cylinder; by Major THOMAS ENGLISH, R.E., Superintendent, Royal Carriage Department, Woolwich.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated, shortly before Ten o'clock. The attendance was 56 Members and 39 Visitors.

ON THE RESULTS OF BLAST-FURNACE PRACTICE WITH LIME INSTEAD OF LIMESTONE AS FLUX.

By the President, CHARLES COCHRANE, Esq.

To Sir Isaac Lowthian Bell we are indebted for a most carefully conducted series of experiments upon the Blast-Furnace, recorded in his work entitled "Chemical Phenomena of Iron Smelting." To M. Grüner is the scientific world further indebted for embodying in his "Études sur les Hauts-Fourneaux" the results of those experiments in the most carefully developed mathematical order and algebraical formulæ that blast-furnace practice has witnessed. Neither M. Valérius nor MM. Flachat Barrault and Petiet have approached Sir Lowthian Bell and M. Grüner in their exposition of the phenomena of the blast-furnace reactions; although, as happens in all scientific progress, those earlier works have been stepping stones to the great stride accomplished by Sir Lowthian Bell and by M. Grüner. It is true that Sir Lowthian Bell pointed out how the presence of carbonic acid in the gases escaping from the blast-furnace had a distinct bearing upon the economy of fuel consumed in the production of a unit of pig iron; but he further insisted on the fact, as he supposed, that there was an absolute limit to the attainable ratio of carbonic acid to carbonic oxide in the escaping gases, beyond which further economy was impossible, by reason of alleged reactions between these two gases as soon as ever that limit was reached. The limit he assigned was one volume of carbonic acid to two volumes of carbonic oxide; which is equivalent to a ratio by weight of three of carbonic acid to four of carbonic oxide or $CO_2 : CO = 0{\cdot}75 : 1{\cdot}00$. M. Grüner gave, presumably for the first time, the maximum of perfection possible in any blast-furnace in terms of the maximum ratio of carbonic acid to carbonic oxide; but he seems too readily to have fallen in with Sir Lowthian

Bell's idea that there was a practical limit to this ratio, by reason of the reactions which Sir L. Bell alleged took place when the limit was exceeded of one volume of carbonic acid to two of carbonic oxide.

The conclusion drawn by Sir L. Bell is believed by the writer to have been experimentally correct under the conditions under which he assumed the gases to exist in the blast-furnace; but the writer's practice has shown him that there are conditions hitherto unrecorded, which govern the attainable ratio of carbonic acid to carbonic oxide; and it has been his aim for many years past to arrive at the true law which governs the relations of these two gases, and the resulting economy or sacrifice of fuel in the blast-furnace. M. Grüner stated that the ratio of carbonic acid to carbonic oxide was the keynote of the position, and he was right; but it has needed years of practical experience, in the light of Sir Lowthian Bell's analytical experiments and of M. Grüner's inferences, to solve the problem.

There are two leading factors in the conduct of a blast-furnace, which are readily intelligible:—the combustion of carbon at the tuyeres into carbonic oxide wholly; and the reduction of the oxide of iron by the reaction of the carbonic oxide thus produced, so as to form carbonic acid, according to the well-known formula in the case of peroxide of iron, $Fe_2\ O_3 + 3\ CO = Fe_2 + 3\ CO_2$ or $(28 \times 2 + 8 \times 3) + 3 \times (6 + 8) = 56 + 3 \times (6 + 16)$. Now supposing there were no other reactions than these, and that there were needed 15 cwts. of pure carbon to produce 20 cwts. of pure iron, the ratio of carbonic acid to carbonic oxide would be found as follows:—$15 \times 14 \div 6 = 35$ cwts. of carbonic oxide produced at the tuyeres; and according to the above formula, for every 56 cwts. of iron 42 cwts. of carbonic oxide would be required with production of 66 cwts. of carbonic acid. Hence for every 20 cwts. of pure iron there would be required $42 \times 20 \div 56 = 15$ cwts. of carbonic oxide; and there would be produced $15 \times 66 \div 42 = 23{\cdot}57$ cwts. of carbonic acid. There would therefore be left $35 - 15 = 20$ cwts. of carbonic oxide; and there would be formed $23{\cdot}57$ cwts. of carbonic acid; and the ratio of these would be $CO_2 : CO = 23{\cdot}57 : 20{\cdot}00 = 1{\cdot}18$. Now Sir Lowthian

Bell's assertion is that such a ratio would be impossible, because the moment the limiting ratio of 0·75 is exceeded, the immediate effect would be to cause a re-conversion of carbonic acid into carbonic oxide, and so to undermine the economy due to such a ratio as the foregoing of 1·18, by the unburning of carbon oxidised to its highest degree. Yet he himself gives an illustration of Styrian furnaces where pig-iron is made with from 12 to 15 cwts. of charcoal per 20 cwts. of pig-iron produced: so that on the merits of the case there would seem to be something wrong in his deductions. Although as a matter of fact so high a value as 0·75 for the ratio of carbonic acid to carbonic oxide has not been attained with Cleveland ironstone, the author purposes showing that the cause is to be sought deeper than in the mere arbitrary limit assigned to the ratio of carbonic acid to carbonic oxide, and is to be found in reactions of carbonic acid upon red-hot carbon, and in the consequent production of carbonic oxide, so that the ratio $CO_2 : CO$ is essentially an effect and not a cause.

In a blast-furnace the perfection of work is that carbonic acid, having once been formed in the process of reduction, should never be allowed to come into contact with red-hot coke; for the immediate reaction between carbonic acid and carbon at a red heat is to convert the carbonic acid into carbonic oxide with most destructive waste of fuel. Thus the units of heat developed by one unit (or cwt.) of carbon burnt into carbonic oxide only are 2,473 (centigrade), whereas the units of heat developed by one unit of carbon burnt into carbonic acid are 8,080; hence the units of heat developed by one unit of carbon in carbonic oxide burnt into carbonic acid are 8,080 − 2,473 = 5,607. It will thus be seen that, if by any unfavourable reaction in the furnace, such as happens when carbonic acid finds itself in the presence of red-hot coke, any carbonic acid once formed becomes re-converted into carbonic oxide, the unburning of the carbonic acid to carbonic oxide must be accompanied not only by the absorption of carbon but also by serious loss of heat. The reaction which takes place is represented by the formula $CO_2 + C = 2\ CO$; in which for every unit of

carbon in the carbonic acid a unit of carbon of the coke is dissolved and becomes carbonic oxide; whilst the unit of carbonic acid becomes two units of carbonic oxide by the absorption of the second equivalent of carbon. Just as one unit of carbon as carbonic oxide develops 5,607 heat-units in becoming carbonic acid, so one unit of carbon as carbonic acid in going back to carbonic oxide will absorb 5,607 heat-units; which is equal to the combustion of $5{,}607 \div 2{,}473 = 2 \cdot 26$ units of carbon burnt into carbonic oxide, of which 1 unit of carbon has absolutely disappeared by absorption in the process, leaving $1 \cdot 26$ units, to be supplied and burnt into carbonic oxide at the tuyeres by means of the oxygen in the blast, to compensate for the balance of loss incurred in the region of the furnace in which the reaction has taken place: because by hypothesis the carbonic acid has been evolved or come into contact with red-hot coke under conditions under which it could not exist as carbonic acid. To make the ultimate result if necessary yet clearer, the absorption of the one unit of carbon by the carbonic acid to form carbonic oxide will develop 2,473 heat-units, while the re-conversion of the carbonic acid to carbonic oxide will subtract from the furnace 5,607 heat-units: so that the balance will be a loss of $5{,}607 - 2{,}473 = 3{,}134$ heat-units, which represent $3{,}134 \div 2{,}473 = 1 \cdot 26$ units of carbon burnt into carbonic oxide. Hence there is a total loss to the efficiency of the furnace of $1 \cdot 26 + 1 \cdot 00 = 2 \cdot 26$ units of carbon burnt into carbonic oxide for every unit of carbon once existing as carbonic acid which shall have been re-converted into carbonic oxide.

When limestone is employed as a flux there are two sources of carbonic acid:—firstly that contained in the carbonate of lime $CaO\ CO_2$, which has necessarily to be evolved in contact with red-hot coke, because at less than a red heat it is impossible to separate the carbonic acid from the lime; and secondly that evolved in the process of reduction of the ore or ironstone, which, if previously calcined so as to become peroxide of iron, undergoes the following reaction: $Fe_2\,O_3 + 3\ CO = Fe_2 + 3\ CO_2$. Now according to the construction of the furnace, and the more or less imperfect appliances at command, much or little of the latter, which will be called the

carbonic acid of reduction, may be evolved in the same red-hot region in which the carbonic acid from the flux is driven off. In old furnaces of very small capacity, extravagant waste of fuel took place from this very cause, namely the evolution of carbonic acid of reduction in the red-hot region, owing to the plunging of the ironstone down into that region before its complete reduction had been effected in a higher and cooler region. How great could be the mischief will appear by assuming the extreme case of a furnace so badly constructed that the whole of the reduction of the peroxide of iron should take place in the red-hot region. From the formula $Fe_2 O_3 + 3 CO = Fe_2 + 3 CO_2$, or $(2 \times 28) + 3 \times 8 + 3 \times (6 + 8) = (2 \times 28) + 3 \times (6 + 16)$, it will be seen that for the reduction of 56 cwts. of iron there are required 18 cwts. of carbon as carbonic oxide; and $56 : 20 :: 18 : 6 \cdot 43$; therefore $6 \cdot 43$ cwts. of carbon are required for the reduction of 20 cwts. of iron from its assumed condition of peroxide. But inasmuch as 20 cwts. of pig-iron contain only $18 \cdot 80$ of pure iron, the carbon required per ton of pig-iron will be $6 \cdot 43 \times 18 \cdot 80 \div 20 = 6 \cdot 04$ cwts. Now suppose the whole of this carbon, which should in a perfect furnace pass away as carbonic acid, became re-converted into carbonic oxide; it would first absorb $6 \cdot 04$ cwts. of carbon for conversion into carbonic oxide, according to the reaction $CO_2 + C = 2 CO$; and the heat to be furnished at the tuyeres would be $6 \cdot 04 \times 1 \cdot 26 = 7 \cdot 61$ cwts. of carbon burnt into carbonic oxide. Hence a total loss would arise of $7 \cdot 61 + 6 \cdot 04 = 13 \cdot 65$ cwts. of carbon per ton of pig-iron.

It was in the direction of reducing this mischievous tendency that, at Middlesbrough especially, important economies ensued on increasing the capacity of the blast-furnace from 6,000 or 7,000 cubic feet to 20,000 cubic feet or more. Thereby more time was given for the reduction of the ironstone: so that it became more possible to secure, in the analysis of the escaping gases when employing limestone as flux, a nearer approach to the presence of the entire quantity of carbonic acid of reduction and in certain cases even the entire quantity. Indeed M. Grüner was quick to discover in Sir Lowthian Bell's experiments the presence in some cases of a little more carbonic acid than was due to the possible formation of

carbonic acid by the reduction of all the ironstone; and the excess must have proceeded from the evolution of carbonic acid from the limestone. As the writer has himself on several occasions since confirmed M. Grüner's observation, he now deems such increase of carbonic acid beyond the carbonic acid of reduction to be the result of a trifling wave of carbonic acid displaced from the surface of the limestone just before it plunges into the red-hot coke region. The amount is so little as not to disturb the main conclusion that the carbonic acid of the flux takes up a weight of carbon practically equal to that which it already contains. Nor must it be lost sight of that in thus taking up carbon and becoming 2 CO the result it produces is not altogether prejudicial; for the carbonic oxide so formed enriches the deoxidising gas of the furnace, and promotes the more complete deoxidation of the ironstone in the cooler region above, so as to make it possible to attain to a perfect reduction thereof without absorption of carbon by carbonic acid of reduction.

At this stage it may be interesting to refer to the effect of displacing the carbonic acid from the flux by calcining the latter before employing it in the blast-furnace. The following Tables 1 and 2 present a comparison between the results obtained at the same furnace under the two different conditions, and will fully illustrate the benefit to be obtained under favourable conditions by the substitution of lime CaO for limestone CaO CO_2 in a blast-furnace of capacity adapted to the materials employed, although there may seem room for a little regret that the balance of heat received (Table 1) and heat expended (Table 2) is not somewhat closer than here appears.

In these comparative accounts of receipts and expenditure of heat it will be noticed that, in working on limestone, the expenditure falls short by 0·72 cwt. of carbon of the total heat received in fuel and heated blast, and reckoned in carbon burnt to carbonic oxide; whilst in working on lime, the expenditure account shows an excess of 0·81 cwt. of carbon over that which was received. These are errors on either side, amounting to $2\frac{1}{2}$ and 3 per cent. respectively, to which calculations of this kind are liable,

TABLE 1.—*Ormesby Iron Works, Middlesbrough.*
Blast-Furnace of 20,454 *cubic feet capacity, and* 76 *feet height.*
Comparison between working
on Limestone and on Lime respectively as flux.

SUPPLY OF HEAT per ton of pig-iron made.	Working on Limestone.	Working on Lime.
	Per cent.	Per cent.
Chemical Composition of the Escaping Gases. By Volume: Nitrogen N	58·28	59·90
Chemical Composition of the Escaping Gases. By Volume: Carbonic Acid CO_2	9·25	9·79
Chemical Composition of the Escaping Gases. By Volume: Carbonic Oxide CO	30·89	28·95
Chemical Composition of the Escaping Gases. By Volume: Hydrogen H	1·58	1·36
Chemical Composition of the Escaping Gases. By Weight: Nitrogen N	56·19	57·43
Chemical Composition of the Escaping Gases. By Weight: Carbonic Acid CO_2	14·04	14·80
Chemical Composition of the Escaping Gases. By Weight: Carbonic Oxide CO	29·66	27·68
Chemical Composition of the Escaping Gases. By Weight: Hydrogen H	0·11	0·09
Ratio of CO_2 to CO by weight . . . . . . ratio	0·473	0·535
Temperature of Blast . Fahr. 1485° and 1409° = centig.	807°	765°
Temperature of Escaping Gases, Fahr. 621° and 574° = centig.	327°	301°
	Cwts.	Cwts.
Coke consumed per ton of pig iron	23·28	19·49
Deduct: Ash . . 7·70 and 7·65; Sulphur . . 0·84 and 0·90; Moisture . . 0·53 and 1·95 — Per cent. 9·07 and 10·50 =	2·09	2·05
Net Carbon in coke consumed per ton of pig iron . . .	21·19	17·44
Limestone consumed per ton of pig iron	13·18	* 7·86 / *12·28
Deduct foreign matter in flux $3\frac{1}{2}$ and 3·71 per cent. . .	0·46	0·45
Net pure Carbonate of Lime CaO CO_2	12·72	11·83
Carbon contained in flux, $12·72 \times 6 \div 50$ and* $0·79 \times 6 \div 22$	1·52	*0·22
Total Carbon supplied into furnace per ton of pig iron, $21·19 + 1·52$ and $17·44 + 0·22$	22·71	17·66
Deduct Carbon absorbed by pig iron	0·60	0·60
Net Carbon for producing joint CO_2 and CO	22·11	17·06

(*continued on next page*)

* When working on lime, the actual weight of flux charged into the furnace per ton of pig iron made was 7·86 cwts. of impure lime, resulting from the calcination of 12·28 cwts. of raw limestone. The latter was found by analysis to contain 3·71 per cent. of foreign matter, amounting therefore to 0·45 cwt.; and the net pure carbonate of lime was accordingly $12·28 - 0·45 = 11·83$ cwts. of CaO CO_2, which contained $11·83 \times 22 \div 50 = 5·21$ cwts. of CO_2. But instead of the whole of this CO_2 being expelled from the limestone in the calcining kiln, the actual weight driven off was only $12·28 - 7·86 = 4·42$ cwts. Consequently there remained in the lime used as flux $5·21 - 4·42 = 0·79$ cwt. of CO_2; and this unexpelled CO_2 contained $0·79 \times 6 \div 22 = 0·22$ cwt. of carbon, which corresponds with 1·83 cwt. of CaO CO_2.

TABLE 1 (*continued*).

SUPPLY OF HEAT (*continued*) per ton of pig-iron made.	Working on Limestone.	Working on Lime.
	Cwts.	Cwts.
Carbon required per ton of pig iron for perfect reduction	6·04	6·04
If all CO_2 passed away without change, total CO_2 in escaping gases would be $(1·52 + 6·04 = 7·56) \times 22 \div 6$	27·72	
and $(0·22 + 6·04 = 6·26) \times 22 \div 6$		22·96
Whilst there would then pass away as CO $(22·11 - 7·56 = 14·55) \times 14 \div 6$	33·95	
and $(17·06 - 6·26 = 10·80) \times 14 \div 6$		25·20
In that case the furnace would be working perfectly with	Ratio.	Ratio.
ratios $CO_2 : CO = 27·72 \div 33·95$ and $22·96 \div 25·20$	0·816	0·911
But the actual working ratios given above were	0·473	0·535
This reduction of ratios, as will be explained further on, is attended with transfer of Carbon from condition of CO_2 to	Cwts.	Cwts.
that of CO, amounting to	2·44	1·93
The transfer, as will also be explained, is derived from the two following sources:—		
Carbon from CO_2 of flux, as above	1·52	0·22
Carbon from CO_2 of reduction, by difference	0·92	1·71
Total Carbon transferred per ton of pig iron, as above	2·44	1·93
Moisture in atmosphere per cubic foot . . . grains	4·776	3·243
Weight of Air supplied into furnace is found as follows:—	Cwts.	Cwts.
Carbon supplied for producing CO_2 and CO, as above	22·11	17·06
Deduct Carbon transferred from CO_2 of flux and of reduction, as above	2·44	1·93
Net Carbon to be converted into CO by Air	19·67	15·13
Weight of Oxygen required $19·67 \times 8 \div 6$ and $15·13 \times 8 \div 6$	26·23	20·17
Weight of Nitrogen required $26·23 \times 77 \div 23$	87·82	
and $20·17 \times 77 \div 23$		67·52
Total Weight of dry Air required per ton of pig iron	114·05	87·69
Total Heat supplied into furnace by blast, reckoned in cwts. of Carbon burnt into CO, each unit of carbon thereby developing 2,473 heat-units, and specific heat of air being 0·239	Cwts.	Cwts.
$\frac{114·05 \times 807° \times 0·239}{2473}$ and $\frac{87·69 \times 765° \times 0·239}{2473}$	8·89	6·48
If to this heat so measured be added the actual Carbon contained in the coke	21·19	17·44
and also the Carbon in the flux	1·52	0·22
There is a total of Carbon to be accounted for as supplied into the furnace, both directly as carbon and in its equivalent of heat carried in by the hot blast, amounting per ton of pig iron to	**31·60**	**24·14**

TABLE 2.—*Ormesby Iron Works, Middlesbrough.*
Blast-Furnace of 20,454 *cubic feet capacity, and* 76 *feet height.*
Comparison between working
on Limestone and on Lime respectively as flux.

EXPENDITURE OF HEAT per ton of pig-iron made.	Working on Limestone.	Working on Lime.
Gases escaping at tunnel head are found as follows :—	Cwts.	Cwts.
Net Carbon for producing CO_2 and CO, as before . . .	22·11	17·06
Deduct Carbon escaping in CO_2, 6·04 − 0·92 and 6·04 − 1·71	5·12	4·33
Leaves Carbon escaping in CO	16·99	12·73
CO_2 escaping 5·12 × 22 ÷ 6 and 4·33 × 22 ÷ 6 . .	18·77	15·88
CO escaping 16·99 × 14 ÷ 6 and 12·73 × 14 ÷ 6 . .	39·64	29·70
Nitrogen escaping, as before	87·82	67·52
Total Weight of dry Gases escaping	146·23	113·10
Heat carried away by waste gases, reckoned in cwts. of Carbon burnt into CO, each unit of carbon thereby developing 2,473 heat-units, and specific heat of escaping gases being 0·237 $\frac{146 \cdot 23 \times 327^\circ \times 0 \cdot 237}{2473}$ and $\frac{113 \cdot 10 \times 301^\circ \times 0 \cdot 237}{2473}$	Cwts. 4·58	Cwts. 3·26
Carbon absorbed by pig iron, as before	0·60	0·60
Carbon absorbed by CO_2 of flux 1·52 and 0·22; Carbon absorbed by CO_2 of reduction 0·92 and 1·71 . .	2·44	1·93
Extra Carbon needed to be burnt into CO at tuyeres for meeting loss of heat due to *un*burning of CO_2 into CO, 2·44 × 1·26 and 1·93 × 1·26	3·07	2·43
Heat required to drive off CO_2 from flux, reckoned in cwts. of Carbon burnt into CO, each unit of flux requiring 373·5 heat-units to drive off CO_2, 12·72 × 373·5 ÷ 2473 and 1·83 × 373·5 ÷ 2473	1·92	0·27
Decomposition of Moisture in blast	1·33	0·73
Carbon remaining as CO_2 and passing away as such in escaping gases is 6·04 − 0·92 and 6·04 − 1·71 . .	5·12	4·33
The Slag, weighing about 32 cwts. per ton of pig iron, requires for its melting 550 heat-units per unit of slag, or 32 × 550 ÷ 2473 of Carbon burnt to CO . . .	7·11	7·11
Melting of the Iron requires	0·90	0·90
Evaporation of Water from coke	0·03	0·09
Sundries, including loss of heat by tuyere water, radiation from sides of furnace and tuyere houses, &c. . . .	3·78	3·30
Total Carbon accounted for as expended	30·88	24·95
Error	+ 0·72	− 0·81
Total Carbon to be accounted for as received	**31·60**	**24·14**
Consumption of calcined Ironstone per ton of pig iron . cwts.	50·13	50·00
Make of Pig Iron per month . . . . tons	2141	2453
Quality of Pig Iron . . . . No.	3·25	3·31
Blast, pressure per square inch at tuyeres . . . . lbs.	3·87	3·73
Area of Tuyeres . . . . . . square inches	142	142

owing to the impossibility of recording accurately all the conditions under which a blast-furnace works. Imperfectly calcined ironstone for instance will contain more or less carbonic acid, which if at the surface will pass away as such, but if imprisoned in the core of a large piece of ironstone will descend into the red-hot region of the blast-furnace, there to be liberated with absorption of carbon and resultant loss of heat. Such fluctuations in the ironstone would produce some influence upon the ratio of carbonic acid to carbonic oxide; but all things considered, the above errors of 0·72 and 0·81 cwt. respectively might fairly be spread over the whole of the expenditure account, indeed probably over both receipt and expenditure accounts, and so become inappreciable whilst leaving the salient points of the account undisturbed.

It will be seen that when working on lime, with even an imperfect calcination of the flux, an economy was obtained of $21 \cdot 19 - 17 \cdot 44 = 3 \cdot 75$ cwts. of carbon; whereas the theoretical saving should have been only 2·94 cwts. of carbon, according to the weight of carbon in the carbonic acid displaced from the flux, namely $(1 \cdot 52 - 0 \cdot 22 = 1 \cdot 30) \times 1 \cdot 26 + 1 \cdot 30 = 2 \cdot 94$.

The calculation which needs explanation in Table 1 is the one whereby, from an analysis of the gases and from a knowledge of the carbon consumed per ton of pig-iron and of the unexpelled carbonic acid in the flux, it is possible to arrive at the exact mischief done in the red-hot coke region by each of the two sources of that mischief, namely the carbonic acid of reduction and the carbonic acid from the flux. In his last paper read before this Institution in January 1883 the author showed how this could be accomplished by a laborious method of calculation and by special tables; but continued study has enabled him to simplify the calculation, and by a simple algebraical formula to test the effective working of a blast-furnace by accounting in the form of an expenditure column for every unit of carbon consumed, whether in the heating of the blast or in the carbon burnt within the furnace. His own practice is to account in this expenditure for all fuel by reducing it to units of

carbon burnt to carbonic oxide, each unit thereby developing 2,473 centigrade units of heat. In this way he hopes to have made a complicated problem clear.

Taking from Table 1 the ratio 0·473 determined by analysis as that of carbonic acid to carbonic oxide in the escaping gases when working on limestone, we begin by ascertaining what this ratio should have been, had there been no re-conversion whatever of carbonic acid into carbonic oxide. Then would the furnace have worked perfectly, and the ratio would have been found as follows. The net carbon available for producing joint carbonic acid and carbonic oxide has been found in the foregoing statement to be 22·11 cwts per ton of pig-iron. In perfect work all carbonic acid should pass away as such; and the total quantity produced in the furnace will be that from the 6·04 cwts. of carbon for the reduction of the ironstone and that from the 1·52 cwt. of carbon in the flux, namely:—

Carbon for reduction .	$6 \cdot 04 \times 22 \div 6 =$	22·15 cwts. of carbonic acid.
Carbon of flux . . .	$1 \cdot 52 \times 22 \div 6 =$	5·57 cwts. of carbonic acid.
Total Carbon . . .	$7 \cdot 56 \times 22 \div 6 =$	27·72 cwts. of carbonic acid.

If these 7·56 cwts. of carbon all appeared as carbonic acid in the escaping gases, the balance should pass away as carbonic oxide, namely $22 \cdot 11 - 7 \cdot 56 = 14 \cdot 55 \times 14 \div 6 = 33 \cdot 95$ cwts. of carbonic oxide. Therefore the perfect ratio of carbonic acid to carbonic oxide would be $27 \cdot 72 \div 33 \cdot 95 = 0 \cdot 816$; but the actual ratio determined by analysis was only 0·473, and has been lowered from the perfect to the actual by the transfer of a certain amount of carbon from the condition of carbonic acid to that of carbonic oxide. Let x be the weight of the carbon so changed; then from the total carbonic acid possible in perfect work there will have been subtracted $\frac{22}{6}x$, and to the total carbonic oxide possible in perfect work there will have been added $\frac{14}{6}x$. Hence the new ratio of carbonic acid to carbonic oxide will be $(27 \cdot 72 - \frac{22}{6}x) \div (33 \cdot 95 + \frac{14}{6}x) = 0 \cdot 473$. Whence $x = 2 \cdot 44$ cwts., as taken in the foregoing Table 1 for the quantity of carbon transferred from the condition of carbonic acid to that of carbonic oxide per ton of pig-iron.

In like manner where lime was employed, containing $0 \cdot 22$ cwt. of carbon as carbonic acid unexpelled, the total quantity of carbonic acid produced in the furnace will be as follows :—

Carbon for reduction .	$6 \cdot 04 \times 22 \div 6 =$	$22 \cdot 15$ cwts. of carbonic acid.
Carbon of flux . .	$0 \cdot 22 \times 22 \div 6 =$	$0 \cdot 81$ cwt. of carbonic acid.
Total Carbon . .	$6 \cdot 26 \times 22 \div 6 =$	$22 \cdot 96$ cwts. of carbonic acid.

If these $6 \cdot 26$ cwts. of carbon all appeared as carbonic acid in the escaping gases, the balance should pass away as carbonic oxide, namely $17 \cdot 06 - 6 \cdot 26 = 10 \cdot 80 \times 14 \div 6 = 25 \cdot 20$ cwts. of carbonic oxide. Whence the perfect ratio of carbonic acid to carbonic oxide would have been $22 \cdot 96 \div 25 \cdot 20 = 0 \cdot 911$; whereas in actual work it fell to $0 \cdot 535$, showing that the carbon transferred from the condition of carbonic acid to that of carbonic oxide amounted to $1 \cdot 93$ cwt. per ton of pig-iron.

It is most important to notice the sources of these two different transfers. Obviously it might fairly be supposed that there should have been a difference between them of $1 \cdot 52 - 0 \cdot 22 = 1 \cdot 30$ cwt.; so that the transfer of $2 \cdot 44$ cwts. in the limestone furnace should have been lowered to $1 \cdot 14$ cwt. in the lime furnace; whereas it appears at $1 \cdot 93$ cwt. Let us therefore examine how the $2 \cdot 44$ and $1 \cdot 93$ are made up in the respective cases of working with limestone and with lime.

	Limestone.	Lime.
Carbon transferred from carbonic acid of flux . .	1·52	0·22
Carbon transferred from carbonic acid of reduction by reason of its evolution in region of red-hot coke	0·92	1·71
	2·44	1·93

With limestone the transfer of $2 \cdot 44$ cwts. of carbon is made up of the $1 \cdot 52$ cwt. of carbon from the carbonic acid of the flux, and only $0 \cdot 92$ cwt. from the carbonic acid of reduction; while with lime the transfer of $1 \cdot 93$ cwt. is made up of the $0 \cdot 22$ cwt. from the carbonic acid of the flux, and no less than $1 \cdot 71$ cwt. from the carbonic acid of reduction, being nearly twice as much from the carbonic acid of reduction when working with lime as when working with limestone.

The use of lime has therefore failed to accomplish some of the benefit which the author ventured to hope and predict in January 1883: thus showing that its employment is not an unmixed good. For through a combination of causes the reduction of ironstone when working with lime as flux has been less effective to the extent of $1 \cdot 71 - 0 \cdot 92 = 0 \cdot 79$ cwt. of carbon per ton of pig-iron, equivalent in the present comparison to a loss of $0 \cdot 79 \times 1 \cdot 26 + 0 \cdot 79 = 1 \cdot 79$ cwt. of carbon per ton of pig-iron. To make this point clearer, in the case of working on limestone the proportion of ironstone reduced in the cooler regions of the furnace out of contact with red-hot coke was $50 \cdot 13 \times 5 \cdot 12 \div 6 \cdot 04 = 42 \cdot 49$ cwts. per ton of pig-iron; whilst there passed down into the red-hot zone for reduction there $50 \cdot 13 \times 0 \cdot 92 \div 6 \cdot 04 = 7 \cdot 64$ cwts. For working on lime the corresponding figures are $50 \cdot 00 \times 4 \cdot 33 \div 6 \cdot 04 = 35 \cdot 84$ cwts., and $50 \cdot 00 \times 1 \cdot 71 \div 6 \cdot 04 = 14 \cdot 16$ cwts. In neither of these cases does the dreaded proportion appear of 1 volume of carbonic acid to 2 volumes of carbonic oxide; for from the analysis given in Table 1 it is seen that the proportion when working on limestone was only $9 \cdot 25 : 30 \cdot 89$ or $1 : 3\frac{1}{3}$, and when working on lime $9 \cdot 79 : 28 \cdot 95$ or $1 : 3$ nearly. The consideration of these volumetric proportions may therefore be dismissed as inoperative in the present instances.

What then are the causes of the diminution in the weight of carbonic acid of reduction—that is, of the increase in the weight of carbon transferred from the carbonic acid of reduction into the condition of carbonic oxide—despite the removal of 85 per cent. of the carbonic acid from the lime used as flux? The causes of this disappointment when working on lime are twofold:—

Firstly, as intimated at the outset (page 592), when limestone is used, all or nearly all the carbonic acid it contains is necessarily converted into carbonic oxide, thus increasing and prolonging the activity of the reducing zone in a cooler region, while at the same time this cooler region is extended downwards by the absorption of the heat due to the unburning of the carbonic acid to carbonic oxide; thus protracting or prolonging the period of reduction of

the ironstone within the extended reducing region: so that the employment of limestone is not an unmixed evil.

Secondly, when lime is used, the weight of carbonic oxide is comparatively diminished, the cool reducing zone is curtailed in its depth, and the total volume of gases is greatly diminished, by reason of the greatly diminished consumption of fuel in the furnace, due to the very economy secured by the previous expulsion of carbonic acid from the flux. When working on lime, the ironstone undergoing the process of reduction is thus subjected both to the passage of a smaller quantity of reducing gas over it, and to that passage during a shorter period of time before entering the red-hot zone, which zone by the use of lime has been raised somewhat higher in the furnace.

To reduce the above conditions to actual figures, we have when working on limestone, according to Table 2, a weight of 146·23 cwts. of gas per ton of pig-iron, which are passing over the materials entering the furnace, and of which 39·64 cwts. consist of carbonic oxide, or 27 per cent. of the total. When working on lime, we have only 113·10 cwts. of gas per ton of pig-iron, passing over the ironstone as it enters the furnace, of which only 29·70 cwts. are carbonic oxide, or 26 per cent. of the total. It will thus be seen that there is only a trifling difference in the percentage of carbonic oxide in the total gases as they leave the furnace: so that, in explanation of the diminished reduction of ironstone in the cooler reducing regions of the furnace when working on lime, there remains the important fact that the materials from which a ton of iron is produced are exposed to the influence of only 29·70 cwts. of carbonic oxide when lime is employed as flux, instead of to that of 39·64 cwts. when limestone is employed: a proportion of about 3 to 4, or 25 per cent. less carbonic oxide when working on lime.

But whilst disappointment has to be confessed to the extent indicated, there are one or two conclusions to be drawn from the above comparisons, which will well reward further consideration.

The air required for consuming the coke per ton of pig-iron is seen from Table 1 to have been in the case of limestone 114·05 cwts., and with lime only 87·69 cwts., showing a direct economy of

26·36 cwts. of air, or 23 per cent.; whilst with the same pressure of blast and the same tuyere area the furnace when working on lime turned out 2,453 tons of iron per month against 2,141 tons per month when working on limestone, Table 2. It is in consequence of this increase in the output that the item of sundries in the statement of expenditure of fuel (Table 2) has been reduced from 3·78 with limestone to 3·30 with lime. It is not generally known how far the constancy of the loss by radiation and by tuyere-water &c. affects the consumption of fuel by reason of increased output; within certain limits this explains the fact that extra driving may be and is accompanied by reduction of fuel consumed to make a ton of iron.

Before passing away from the subject of the smaller quantity of air required to make a ton of iron when lime is employed as flux, it will be proper here to refer to M. Grüner's claim that he was the first to show how, from a knowledge of the quantity of coke consumed and the ratio of carbonic acid to carbonic oxide, the weight of air needed could be accurately ascertained. This in itself was a great stride towards the correct understanding of the phenomena of blast-furnace practice; and the writer has never seen his claim challenged. That method is absolutely correct, and must in any future calculations supersede all other rough and ready methods hitherto in vogue for determining the quantity of air needed.

Attention may here be drawn to two errors into which the author fell in the comparative results given in his paper in 1883. Firstly, he omitted to allow for the carbon needed to melt the ton of pig-iron on which the calculations were based, and was under a misapprehension at the time that it was included elsewhere. Secondly, he also assumed that the total loss of carbon in the transfer of a unit of carbon from the condition of carbonic acid to that of carbonic oxide was 3·26 times the amount of that unit; whereas it should have been 2·26 times:—namely 1 unit absorbed by the carbonic acid in the red-hot region, and 1·26 unit needed to be burnt into carbonic oxide at the tuyeres in order to meet the cooling effect of that absorption. In the present comparison of

limestone and lime an allowance of 0·90 cwt. has been made for melting the 20 cwts. of pig-iron, notwithstanding that M. Grüner adopts Sir Lowthian Bell's figure of 330 calories, which is equivalent to $330 \times 20 \div 2{,}473 = 2 \cdot 67$ cwts. of carbon burnt to carbonic oxide for melting a ton of pig-iron; whereas in practice a good cupola can melt a ton of pig-iron with less than 1 cwt. of coke. The author strongly suspects some error in the determination of heat contained in pig-iron running from a blast-furnace or cupola; and is glad to learn that M. Grüner investigated the matter further after accepting Sir L. Bell's suggested average of 330 calories. In an admirable pamphlet by M. J. Wolters, written in 1876 on the lines of M. Grüner's work, and called "Études sur la fabrication de la fonte blanche pour fer fort au moyen des minettes ou minerais oolithiques du Luxembourg," he refers to M. Grüner's researches on the fusion of white iron, and gives the reduced figure of 265 calories, equivalent to 2·14 cwts. of carbon per ton of pig-iron; but according to actual cupola practice this is still far too high, and the author has always pictured to himself that the blast-furnace must necessarily surpass the average cupola in economy of melting iron: so that he trusts the figure he has adopted of 0·90 cwt. of carbon burnt to carbonic oxide per ton of pig-iron will not be found far from the truth.

Discussion.

Sir Lowthian Bell, Bart., Past-President, said this was not the first time that he and the author of the paper just read had not altogether agreed in their views with regard to blast-furnace work. At the outset he wished to thank him for the very kind expressions he had used with regard to himself in the opening page of his paper. He would also take the opportunity of expressing his own appreciation, and he was sure that of the Members generally, of the very great service that their President had rendered, not only by his elaborate experiments on the working of blast-furnaces, but still more by the candour with which he had communicated to the world the results of his observations.

There were very few who knew better than Mr. Cochrane the great difficulty of forming an opinion with regard to the action of a blast-furnace by the analysis of the escaping gases. The operations were conducted on so large a scale, and the quantity of the material dealt with was so enormous, that it was most difficult for an investigator to satisfy himself that at any particular time he was not dealing with a peculiar and it might be an entirely abnormal condition of the furnace, instead of with an average of its performance. This difficulty he had himself endeavoured to avoid by always devoting a considerable space of time for taking the samples of gas which he wished to analyse, something like two hours being usually devoted to collecting the specimen, during which he fancied that there was a reasonable chance of getting something like an average expression of the conduct of the furnace.

From the paper now read he supposed there could be no doubt that the presence of carbonic acid, in some quantity or other of which he did not find exact information given by the author, was regarded by him, as it had long been by himself, as a very important element in judging of the manner in which the furnace was performing its work. But the question was, to what extent could that carbonic acid be expected to be found in the gases escaping from the blast-furnace: in other words, was there a ratio of carbonic acid to carbonic oxide which could not be exceeded? In the first

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page of the paper he found himself quoted as having said that there was an absolute limit to the action of converting carbonic oxide in a blast-furnace into carbonic acid; and the late M. Grüner was represented as having too readily accepted that heretical doctrine. Now it was perfectly true that he had himself maintained that there was such an absolute limit; but he had never asserted what that absolute limit was, because he did not as yet know it by actual experiment; he had himself performed no experiments, and he thought it would be difficult to perform any experiments, on a blast-furnace scale, in order to ascertain what that particular limit exactly was. At the same time he did not recede one iota from the strong belief which he had often expressed, and which he now expressed again, that in all probability the ratio would never be found to exceed one volume of carbonic acid to two volumes of carbonic oxide. In saying this he did not pretend for a moment that it was impossible by means of peroxide of iron to convert carbonic oxide entirely into carbonic acid; indeed he had himself proved the contrary. That possibility was a fact which he should think was known to every chemist; but what were the conditions to be observed in order to effect this entire conversion? There must be a great excess of peroxide of iron; for it was easy to suppose that a molecule of iron could retain its combined oxygen with varying degrees of energy according to the quantity with which the metal was united. If so, then the first portions of oxygen which were removed from the peroxide of iron might be far more easily separated from the iron than were the last. Then upon what ground did he himself maintain that there was a limit to the quantity of carbonic acid which might be found in the gases escaping from a blast-furnace in comparison with the quantity of carbonic oxide? The author had spoken of his having assigned an arbitrary limit to this ratio; and he should therefore like to recall an experiment which he had performed. He took a quantity of peroxide of iron, heated it red hot, and passed over it a mixture of carbonic oxide and carbonic acid in equal volumes. This mixture of gases at once began to detach the first portions of the oxygen; but as soon as 33 per cent. of the oxygen had been separated from the oxide, thereby reducing

it to protoxide of iron, the mixture of carbonic oxide and carbonic acid of the above composition became entirely inert: that is, it could separate no more oxygen from the iron than the 33 per cent. of that contained in the peroxide. Was it rash then to state that at all events there was a probable limit to the ratio in which carbonic oxide and carbonic acid could exist together in the furnace gases, beyond which the mixture would lose its reducing power? But lest there might possibly be any demur to such a conclusion, the experiment just mentioned had been followed up by another. Instead of taking peroxide of iron, he had taken what was known as spongy iron, that is, oxide of iron which had been exposed in a heated tube to a current of hydrogen until no more water was formed: an indisputable chemical proof that the oxide of iron originally placed in the tube was now perfectly pure metallic iron in its spongy form. Over the pure iron so obtained, and heated in the manner pursued with the peroxide, a current was passed of carbonic oxide and carbonic acid, also in equal volumes, this proportion being the same as that which had sufficed to rob the peroxide of iron of 33 per cent. of its oxygen; and what now took place? The iron instantly began to decompose the carbonic acid, and went on absorbing oxygen from this constituent of the mixture of gases until it had reached the condition of protoxide of iron, that is, until it had reached the same condition at which the peroxide had left off losing oxygen. From these two facts, taken either separately or in conjunction, he did not know what other conclusion could be come to than that in the blast-furnace, with a mixture of those two gases and with either oxide of iron or metallic iron, there was a limit of a most indisputable character to the ratio of the two gases forming a neutral mixture. It was of course to be remembered that the ratio between these two gases was greatly influenced by temperature: more heat was required in order to enable carbonic acid to obtain the mastery as it were over carbonic oxide; for when the temperature was lowered, the mastery of carbonic oxide began to prevail, and the peroxide of iron could be reduced to a much greater extent than it could be at the higher temperature. Hence at the top of a blast-furnace properly constructed and properly conducted there was no difficulty, at a

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temperature say of 300° to 400° centig. or 570° to 750° Fahr., in charging the escaping gases with carbonic acid to the extent of the limit he had mentioned, namely one volume of carbonic acid to something above two of carbonic oxide, reduction of the ore going on up to that point. The present question he presumed was whether the oxidation of the carbonic oxide could be carried further than the extent just mentioned. All he could say was that in the escaping gases of a blast-furnace, and of course at the temperature prevailing in that portion of the furnace, he had left minute specimens of Cleveland ironstone for 96 hours; and at the end of that time he had found only a very slight diminution of the oxygen in the ore. That is to say that an enormous current of heated blast-furnace gases, passing over small quantities of ironstone, was unable in 96 hours to extract from it more than 5 per cent. of its combined oxygen. Was it therefore extravagant to say that, when the gases in the ratio of one volume to two, or thereabouts, were found to be so inert, it looked very much as if there must be a limit to the ratio? None the less in the case of a blast-furnace, as he had already said, it was extremely difficult to get at what was the precise limit. Of course it was a comparatively easy thing to reduce iron ores in a laboratory, and he had done it over and over again with all proportions of the two gases; and there effects were obtained which might easily deceive and mislead from the cause he had mentioned, namely that at first, when there was a comparatively large quantity of oxygen present in combination with iron, it was not difficult to abstract a portion of it. The author had spoken of the late Professor Grüner as corroborating Sir Lowthian Bell's views in his "Études sur les Hauts-Fourneaux," a work which in point of fact, as mentioned in the paper, was in reality an examination of the experiments which he had himself performed and had described elsewhere. Mr. Cochrane agreed in page 590 of his paper with Professor Grüner's opinion that the ratio of carbonic acid to carbonic oxide was the keynote of the position; but then he proceeded to say that it had needed years of practical experience, in the light of Sir Lowthian Bell's analytical experiments and of M. Grüner's inferences, to solve the problem.

Now if he was correct in his apprehension of the paper, the author's meaning must be that there was no limit to the ratio of those two gases.

The President interposed that there was a limit, and he had adopted it in the paper as Professor Grüner's limit (page 589); he had in each case, with limestone and with lime, defined (pages 599 and 600) the limit of carbonic acid for the perfect working of the blast-furnace under the circumstances detailed in Tables 1 and 2.

Sir Lowthian Bell imagined then that the author meant the limit of carbonic acid had been understated by himself, and that this gas might be considerably higher than half the volume of the carbonic oxide. Therefore, if the author dissented from the other interpretation of his meaning, it must be that the author expected a higher limit, that is, a greater proportion of carbonic acid. Was this the correct inference to draw from the paper?

The President considered that the limit might be higher under circumstances different from those of Sir Lowthian Bell's experiments now described.

Sir Lowthian Bell was of opinion that no ordinary difference of circumstances would affect the limit to the ratio of the two gases, and was willing to concede the choice of circumstances in any form. In justification of his own view he had already stated that, when the gases were leaving a large blast-furnace with their reducing capacity satisfied, in no one of the many analyses which he had made, and these at many different furnaces, had he ever found more than an *average* of one volume of carbonic acid to two of carbonic oxide. If this statement were contested in the present paper, it would certainly seem that an extraordinary course was taken for confuting it. For what were the statements made in the paper itself in support of the author's views? One volume of carbonic acid to two of carbonic oxide meant that by weight the mixed carbon gases contained 33 per cent. of their entire carbon in

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the form of carbonic acid. In the paper the author gave his own results; and what were they? In the furnace using raw limestone the analysis of the escaping gases (page 595) showed that only 23 per cent. of their entire carbon was contained in the carbonic acid, equal therefore to 1 vol. of carbonic acid to 3·34 vols. of carbonic oxide: so that in point of fact the proportion of carbonic acid was much less than he had himself almost always found in his experience with large furnaces. It was true that the author said the furnace using raw limestone was working under disadvantageous circumstances by the use of this mineral; and he proposed to remove the defect by calcining the limestone beforehand, and using lime instead; but even then the analysis showed only 25 per cent. by weight as the proportion of carbon contained in the carbonic acid of the gases, or 1 vol. of carbonic acid to 2·95 vols. of carbonic oxide. It would therefore be seen that the limit which he had himself attained for the ratio of carbonic acid to carbonic oxide in the escaping gases was much higher than was shown by the author's practice to be possible in what he appeared to think was the perfection of blast-furnace working.

With regard to the retention of carbonic acid in the gases of a blast-furnace, he had pointed out on previous occasions that the probable result of introducing a very hot blast into the furnace might be to facilitate the action of the coke upon carbonic acid. Referring to the accompanying Table 3, it would be seen that in experiment C the temperature of the blast admitted into the furnace of 80 feet height was 485° centig.; the quantity of heat emitted by one unit of coke (not pure carbon) burnt to carbonic oxide was 2,018 calories, and by the conversion of a certain portion of this carbonic oxide into carbonic acid there was evolved 1,636 calories; and then there was conveyed into the furnace by the blast 534 calories, making a total of 4,188. In experiment D made on the same furnace, but with the blast heated to 695° centig., it would be seen that the total heat evolved was increased to 4,240 calories; but what he would call attention to was this: that, while the quantity of heat which entered the furnace with the blast had risen from 534 to 732 calories, the quantity of heat developed by the carbonic acid

TABLE 3.—*Heat (calories centigrade)*
supplied into Blast-Furnace per unit of Coke burnt.

Experiment	A	B	C	D	Ormesby	
Height of Furnace . feet	48	48	80	80	76	76
Temperature of Blast centigrade	0°	485°	485°	695°	807°	765°
CALORIES.	Cal.	Cal.	Cal.	Cal.	Cal.	Cal.
Per unit of Coke burnt to CO	2,078	2,028	2,018	2,045	2,029	2,120
From portion of CO burnt to CO_2 . . .	560	1,059	1,636	1,463	1,232	1,243
Total calories from Coke .	2,638	3,087	3,654	3,508	3,261	3,363
Calories in Blast . .	0	508	534	732	924	816
Total calories supplied into Furnace . . .	2,638	3,595	4,188	4,240	4,185	4,179

had fallen from 1,636 to 1,463 calories. So that in fact from a purely calorific point of view there had been no advantage whatever from the hotter blast: unless indeed the greater heat brought in by the blast had been obtained by combustion of the waste gases, in which case of course there was a distinct advantage of a purely commercial character. Neither from a calorific nor from a commercial point of view however was there anything like the advantage that had been predicted by those who had first advocated the use of highly heated air; but there was still quite enough to justify its use. Mr. Cochrane's figures in his present Tables 1 and 2 also gave exactly the same result; as compared with experiment C in Table 3, there was a great falling off in the heat evolved from carbonic acid with a hotter blast, as seen from the last two columns in Table 3, which showed the heat evolution per unit of coke in the two cases given in the paper. There was however a marked advantage in the use of highly heated air, namely the diminished volume of escaping gases, as would be seen in Table 4.

With regard to the great question of working on lime instead of on limestone, it was true that when limestone was thrown into a

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blast-furnace it retained its carbonic acid so strongly that, as the author had said in page 592, it only parted with it on arriving at a portion of the furnace where the heat was such as also to decompose the carbonic acid given off by the limestone. Of course that was an inconvenience, and he quite admitted with the author that it would be a very good thing if by working on lime it could be avoided: but the substitution of lime for limestone produced no such result. Because, if a quantity of caustic lime, that is lime from which carbonic acid had been expelled, were heated to a moderate red heat—in fact the action began at a much lower heat than this—it absorbed carbonic acid which at a higher temperature was expelled. He had therefore no doubt whatever in his own mind—he had not been able to prove it, because it was not easy to do in a blast-furnace, but he had proved it over and over again in the laboratory—that caustic lime, at temperatures prevailing in the upper regions of the furnace, absorbed carbonic acid with great rapidity; and he accordingly believed that any advantage gained from its previous calcination ended in its re-absorbing carbonic acid when charged into the blast-furnace. Such carbonic acid, he need scarcely say, would be given off in the hotter zone just the same, and with the same results, as if the carbonate of lime had been in the form of limestone. From the paper it appeared that Mr. Cochrane had found lime of great benefit. But its use had been begun by Mr. Windsor Richards in a blast-furnace of 80 or 90 feet height at Eston; and he should like to hear what he had to say about the practice. He did not know whether at the time of Mr. Richards leaving Eston it had already been discontinued; but it certainly was not being continued at present. Recognising that there was a certain amount of advantage gained in the old furnaces of 48 feet height by calcining the limestone beforehand, he had himself ascertained what was the effect of using lime in a large furnace; and he had then found the result not favourable to the continuance of the plan in large furnaces such as those now used in Cleveland. Messrs. Samuelson also had begun to use calcined lime, and he understood that they still used it for some purposes; but for smelting Cleveland ironstone they had entirely abandoned

TABLE 4.—*Appropriation of Heat in Blast-Furnace per ton of Pig-Iron, in Calories (centigrade) and equivalent cwts. of Coke.*

See foot-note page 614.

Experiment	A		B		C		D	
Height of Furnace, and Temp. of Blast (centig.)	48 feet, and 0°		48 feet, and 485°		80 feet, and 485°		80 feet, and 695°	
Calories (centig.), and equivalent cwts. of Coke	Calories.	Coke.	Calories.	Coke.	Calories.	Coke.	Calories.	Coke.
Constants.		cwts.		cwts.		cwts.		cwts.
Reduction of Fe_2O_3 in ore	33,108	12·550	33,108	9·209	33,108	7·905	33,108	7·808
„ „ Metalloids in pig-iron	4,174	1·582	4,174	1·161	4,174	0·996	4,174	0·981
Dissociation of CO ($2CO = C + CO_2$)	1,440	0·516	1,440	0·400	1,440	0·314	1,440	0·340
Fusion of Pig-Iron	6,600	2·501	6,600	1·836	6,600	1·576	6,600	1·557
Constants per ton of pig-iron	45,322	17·179	45,322	12·606	45,322	10·821	45,322	10·689
Variables.								
Evaporation of Water in Coke	630	0·239	411	0·114	312	0·074	298	0·070
Decomposition of Moisture in Blast	5,420	2·055	3,348	0·931	2,720	0·649	2,408	0·568
Expulsion of CO_2 from Limestone	6,660	2·526	5,920	1·647	5,054	1·207	4,070	0·961
Reduction „ „ „ to CO	6,912	2·620	6,144	1·709	5,248	1·254	4,099	0·962
Fusion of Slag	18,590	7·045	17,325	4·819	16,720	3·993	15,565	3·673
Carried off in Escaping Gases	29,482	11·178	18,486	5·144	11,043	2·636	8,906	2·101
„ „ Tuyere Water, Radiation &c.	5,694	2·158	7,011	1·950	7,057	1·686	9,389	2·216
Variables per ton of pig-iron	73,388	27·821	58,645	16·314	48,154	11·499	44,735	10·551
Sum of *Constants* and *Variables*	118,710	45·000	103,967	28·920	93,476	22·320	90,057	21·240
Weight of Blast per ton of pig-iron . cwts.		228		128		103		91
Weight of Escaping Gases . . . cwts.		285		170		138		126
Weight of Slag . . . . . cwts.		34		31		29		28
Weight of Limestone . . . . cwts.		18		16		12		11

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it. As resulting from a condition of things which he himself was quite certain did not in reality exist, an economy of 3·75 cwts. of carbon per ton of pig-iron had been put down in the paper (page 598) as obtained by working on lime. Assuming however that caustic lime did not re-absorb carbonic acid, and consequently had none to give off in the hot zone where its presence was hurtful, he apprehended the saving of 3·75 cwts. of carbon had been over-estimated in the paper. In the accompanying Table 4 was shown the heat absorbed in the various stages in smelting iron ore in different sized blast-furnaces. Taking the last instance D of a furnace 80 feet high, using about the same quantity of limestone as was consumed at Ormesby, it would be seen that the number of calories absorbed in expelling the carbonic acid from the limestone was 4,070 per ton of pig-iron, and the heat absorbed in reducing the carbonic acid from the limestone to carbonic oxide was 4,099 calories; making together 8,169 calories. Now the coke burnt in furnace D per ton of pig-iron had been 21·24 cwts., and the number of calories represented by that consumption had been 90,057. Hence the foregoing 8,169 calories would represent in the same furnace only 1·92 cwt. of coke. It was therefore clear that in the furnace it would be found impossible to save 3·75 cwts. of carbon per ton

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Foot-note to Table 4, page 613.—The factors from which the heat absorbed is estimated in Table 4 are taken from the average determinations of the best authorities on the subject, and occasionally verified, where necessary, in the laboratory of the Clarence Iron Works. To ascertain the equivalents in coke, the calories so obtained are divided by the heat obtained from burning each unit of coke. Thus in furnace D, $90{,}057 \div 4{,}240 = 21 \cdot 24$ cwts. of coke, made up of the items given under this head. If, as contended by the author, the divisor should be 2,473 calories (carbon burnt to carbonic oxide), the coke consumed for any object will be correspondingly increased; and thus 3·75 cwts. have been obtained in the paper, instead of 1·92 cwts. as stated in Table 4. That which is contended for in regard to this one item is applicable to all; therefore $90{,}057 \div 2{,}473 = 36 \cdot 42$ cwts. of carbon; and allowing 10 per cent. for ash in the coke, $36 \cdot 42 \times 100 \div 90 = 40 \cdot 47$ cwts. of coke, the quantity used being 21·24 cwts. of coke. In support of the general correctness of the figures made use of in Table 4 may be adduced the fact that the calculation of the heat evolved in the case of furnace D was 89,838 calories against 90,057 calories appropriated.

of pig-iron by merely calcining the lime, for the simple reason that it did not take at the outside so much as 2 cwts. of coke to effect both the expulsion of the carbonic acid from the limestone and its reduction into carbonic oxide. He accordingly began to consider for himself to what the alleged economy of 3·75 cwts. of coke was due. The limestone furnace was put down in page 595 as consuming 23·28 cwts. of coke per ton of pig-iron. But in the author's paper in 1883 the consumption of fuel in May 1882 in the same furnace using limestone had been given as 21·45 cwts. of coke per ton of pig-iron (Proceedings 1883, page 119). What had happened to that furnace since 1882? It was still working on limestone as it did then; but instead of still using only 21·45 cwts. of coke, it was now using 23·28 cwts. If so, why not compare its former instead of its present rate of consumption—that is 21·45 cwts. instead of 23·28 cwts.—with the 19·49 cwts. now ascribed in Table 1 to the use of lime?

There was another matter that he wished to point out. The author looked for the day (page 593, line 19)—and he was afraid he would have to look for it for a very long time—when a *perfect* reduction of oxide of iron would be accomplished in the cooler region of the furnace, that is, at the top. He said this because if, instead of charging ironstone into the furnace, metallic iron—spongy iron—were so treated, and if nothing but pure carbonic oxide were present there: that iron he believed would combine with something like 20 per cent. of the oxygen originally contained in peroxide of iron. The explanation of this action was probably due to the fact that, when carbonic oxide was passed over either oxide of iron or even over metallic iron, at a moderate elevation of temperature, there was a decomposition of the carbonic oxide, carbon being precipitated and carbonic acid formed. Essentially the action was represented by the formula $2\,CO = C + CO_2$; but in reality it was of a much more complicated character. It was of importance however to mention that accompanying this reaction some iron was oxidised, or some of the oxide of iron escaped reduction. If it were urged that what happened in the laboratory might not take place in the blast-furnace, he would refer to the accompanying Table 5, in

TABLE 5.

Weight of Oxygen and Carbon in Blast-Furnace Gases per ton of Pig-Iron, at different depths below top of minerals in furnace.

Depth below top of minerals.	No. 1 furnace.		No. 2 furnace.		No. 3 furnace.		No. 4 furnace.	
	Oxygen.	Carbon.	Oxygen.	Carbon.	Oxygen.	Carbon.	Oxygen.	Carbon.
Feet.	Ton.	Ton.	Ton.	Ton.	Ton.	Ton.	Ton.	Ton.
0	1·843	1·101	1·843	1·104	1·670	1·048	1·670	1·048
8½	1·250	0·864	...	...	1·309	0·926	1·271	0·897
18	1·235	0·816	1·410	0·914	1·206	0·907	1·224	0·898
31	1·234	0·871	1·482	1·046	1·312	0·918	1·300	0·917
44½	1·236	0·904	1·190	0·894	1·256	0·946	...	...
57	1·207	0·899	1·207	0·887	1·253	0·931	1·261	0·926
62½	1·137	0·890	1·255	...	1·253	0·939	1·285	0·977
68	1·348	0·967	1·366	0·927	1·378	1·013	1·387	1·021

A depth of 8 feet immediately below the charging plates is occupied by charging apparatus.

Furnaces No. 3 and No. 4 were using partially calcined limestone; hence the deficiency of oxygen and carbon until the lower depths are reached.

which were given the weights of oxygen and of carbon in the gases at different depths below the top of the charge in four furnaces, per ton of pig-iron produced. Comparing in No. 1 furnace the respective weights between 62½ and 68 feet depth, it would be seen that the weight of oxygen in the gases increased from 1·137 to 1·348 ton near the tuyeres, at the same time that the carbon increased from 0·890 to 0·967 ton per ton of pig-iron. How were these additional quantities to be accounted for? In his opinion they were due to oxygen being absorbed from carbonic oxide, either by metallic iron or by some suboxide of iron, through the action which he had just explained. Carbon had been precipitated from the carbonic oxide simultaneously with a retention or absorption of oxygen by the iron. The oxygen and carbon thus communicated to the ore were retained

until they reached the tuyeres, where both were returned to the gases. It would be observed that in each of the examples given in Table 5 the increase of oxygen and carbon in the gases was found to take place. In page 594 of the paper the slight excess of carbonic acid discovered in the escaping gases had been spoken of as proceeding from a trifling wave of carbonic acid displaced from the surface of the limestone; but that view he thought was a mistaken one, for he believed the excess of carbonic acid in the escaping gases, and of oxygen and carbon at the lower depths he had referred to, had probably also proceeded from the dissociation of carbonic oxide in the presence of oxide of iron or metallic iron in the manner already described.

By way of controverting any such limit as one volume of carbonic acid to two of carbonic oxide for the ratio of these two gases escaping from the blast-furnace, reference had been made in page 591 of the paper to Styrian furnaces, in which, in a paper that he had himself read at Vienna (Iron and Steel Institute Journal 1882, page 534), he had mentioned 15 cwts. of charcoal as sufficing to produce one ton of pig-iron. In the present paper it appeared to be thence inferred that there must surely have been a great quantity of carbonic acid in the escaping gases, in order to account for so low a consumption as only 15 cwts. of charcoal. But on referring to Table 4, page 613, it would be seen what an extraordinary amount of coke was absorbed in what he had called the variable sources of appropriation of heat. For the fusion of the slag in furnace D the quantity of coke required was no less than 3·673 cwts. per ton of pig-iron; and he might go on to point out that all those variables fluctuated greatly, according to the class of ore which was being smelted. Thus instead of requiring, like furnace D, more than 90,000 calories per ton of pig-iron produced, the Styrian furnaces, using 15 cwts. of charcoal, required only 60,000 calories. It was therefore easy to understand how so small a consumption of charcoal might suffice, and how nevertheless the furnaces might still retain the ratio of one volume of carbonic acid to two of carbonic oxide or thereabouts, as happened in the gases escaping from the larger furnaces working in Cleveland with a higher consumption of fuel.

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With regard to the quantity of fuel required for melting a ton of pig-iron, there appeared to him to be a mistake in the mode of making the calculation in page 604 of the paper. His own assumption had been that 330 calories were required to melt one cwt. of iron; and the author had properly multiplied that by 20, and got 6,600 calories for melting a ton of iron; but then he proceeded to divide this product by the number 2,473. It was true that 2,473 calories might be assumed as the product of burning carbon into carbonic oxide; but was all the heat in the blast to be neglected, and all the carbonic oxide that was burnt into carbonic acid? In point of fact, as he had already shown in Table 3 (page 611), the quantity of heat obtained from the coke and from the blast in furnace D, instead of being 2,473 calories, was 4,240; and when the 6,600 calories came to be divided by 4,240, the result was something like 1½ cwt. of coke per ton of iron, instead of the 2·67 cwts. mentioned in the paper. It was stated in page 604 that in practice a good cupola could melt a ton of iron with less than 1 cwt. of coke; and although he had never succeeded in doing this himself, he would not question it, but would accept the assurance that it was done. The author however had taken no account at all of the fact that coke burnt in a cupola was burnt under different conditions from those under which it was burnt in a blast-furnace. In a low furnace, such as a cupola, he should himself be much surprised if the gases escaping did not contain a notable quantity of carbonic acid; and he need not point out the great difference which that would make in the consumption of fuel.

With reference to the remarks in page 602 of the paper about the reduction in the quantity of air in the furnace when working on lime, it seemed to be implied that this reduction was due to having converted the limestone beforehand into lime. In his own opinion however it was not due to that cause. The quantity of air consumed in the furnace when using limestone had been increased, not on account of the carbonic acid that was in the limestone, but because the furnace had then to burn 3¾ cwts. more coke per ton of pig-iron, which quite accounted for the difference in the quantity of blast required.

Mr. E. Windsor Richards, Member of Council, said the question of using lime instead of limestone in the blast-furnace had often exercised the minds of blast-furnace managers. It would seem natural that by putting in a purer material an economy of fuel should result. In January 1885 he had determined to try the experiment upon five very large blast-furnaces at Eston, Nos. 4, 5, 6, 7, and 8, using Cleveland ironstone; and had continued the experiments till October 1885. The burden was not altered; the furnaces carried neither a lighter nor a heavier burden. The only result obtained was that the furnaces drove better; they turned out a larger quantity of iron per fortnight; but there was no economy whatever in fuel. The average make of iron per fortnight in the five furnaces together when using limestone was 6,505 tons, and their make of iron during the seventeen fortnights of using calcined lime was 7,220 tons: showing that each furnace made about 70 tons more per week. There was no economy whatever in the fuel, not even sufficient to pay for the cost of calcining, although very large kilns were used, of 45 or 50 feet height, which took perhaps only about one ton of small coal to calcine about 30 tons of Cleveland ironstone. Of course in times like the present, when about 10*s.* a ton more could be got for the pig-iron than formerly, ironmasters might like to be able to make the extra 70 tons per week; but this did not bear upon the present question. Not being himself a chemist, he was unable to say what the proportion of carbonic acid to carbonic oxide in the escaping gases should be; but a few years ago he had spent for Messrs. Bolckow Vaughan and Co. some £60,000 in improving their six blast-furnaces at South Bank, and had naturally been anxious to obtain the best possible results. Reading and hearing a great deal about the proportions of carbonic acid to carbonic oxide, he thought he would try to have the proportion as nearly correct as possible; and so he employed Mr. Stead, whom all knew as one of the most careful chemists of the time. Observations were taken twice a day for about six months, which was no small matter; and the analysis of the gases showed that the proportion of carbonic acid to carbonic oxide varied every now and then, sometimes considerably. The blast-furnaces however did not take any notice

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of the variation, but went on working remarkably well; and so he was obliged to leave it to others to settle the question of the precise proportion of the two gases. If it were possible to thrash out this question on neutral ground, he was sure that the proprietors of the Low Moor Iron Works would be very happy indeed to place one, two, or three of their cold-blast furnaces at the disposal of the President and Sir Lowthian Bell, in order that they might there ascertain whether there was any economy in using lime against limestone, and might also arrive at a solution of the vexed question as to the proportions of carbonic acid and carbonic oxide.

Mr. Edward P. Martin, Member of Council, gathered from the present paper that, while using caustic lime in a high blast-furnace might perhaps come to nothing, using caustic lime in low furnaces might have a beneficial effect. He intended trying it himself shortly in a low blast-furnace.

Mr. David Evans, having been connected with blast-furnaces all his life, agreed with Mr. Martin in thinking it an advantage to use lime in low furnaces. Formerly in South Wales he had been the manager of furnaces of 45 feet height at Aberdare and at Rhymney, and had found a considerable advantage in using lime; a larger output was obtained, and also, if he remembered rightly, a considerable saving in consumption of fuel. At Barrow, where he was now manager, nothing but limestone was being used, because there was no means of calcining it there; and therefore he could not express any opinion as to what economy there might be in using lime for smelting hematite ores in the Barrow furnaces of 60 to 65 feet height: although in the lower furnaces in South Wales of about 45 feet height considerable benefit had been found in using lime as against limestone.

Sir Lowthian Bell said he too had found benefit from using lime in the case of low blast-furnaces.

The President scarcely knew how to reply to much of what had been said. His difficulty arose from the introduction of matter

which he had not introduced into his paper: especially those early experiments (pages 606–7) in reference to the effect of a mixture of carbonic acid and carbonic oxide upon oxide of iron and spongy iron respectively. He would admit unhesitatingly that Sir Lowthian Bell's experiments were correctly made and recorded; but they did not bear upon the blast-furnace in the proper conditions under which a blast-furnace ought regularly to work. There were of course circumstances in blast-furnace working where awkward conditions came into play; but what he aimed at was to remove the furnace from the sphere of operation of those awkward conditions; it was therefore beside the purpose of his paper to go further into that matter.

That Sir Lowthian Bell should have introduced the subject of highly heated air (page 610) was also a difficulty, because in the paper the temperature had been kept nearly the same: the comparison had been made between two furnaces working on lime and on limestone with about the same temperature of blast, or as nearly so as could be practically obtained over two or three months at a time; and he had chosen the conditions so that there should be no objection raised to the fluctuation of temperature, and that there should be no corrections to make on that score at all; he had thus eliminated the question of blast temperature, and had not expected it to be raised. It was indeed superfluous to discuss at the present day the old question fought out so long ago of the value of a high temperature of blast. It was pretty well admitted, by the general application of highly heated blast, that at any rate it had some merits; but it did not bear at all upon his present paper.

As regarded the belief that caustic lime heated to a high temperature would absorb carbonic acid with great rapidity (page 612), this was an opinion against which he had all along had to fight; for he well recollected, from himself sitting at his feet twenty years ago, how Sir Lowthian had then condemned the use of caustic lime, and had taken him to a kiln in which the lime was being burnt for testing the question, and had told him it was found perfectly useless to burn it, as it was not worth the trouble, and the kiln was consequently about to be let out. He was

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not surprised therefore to hear Sir Lowthian endorse that opinion now, and confirm it by even more recent experience. He had himself ever since had to fight against the prejudice so created in his own mind, that caustic lime ought not to be introduced into a blast-furnace; and he had therefore brought this paper forward to show that there were conditions under which caustic lime if properly applied would give more than the theoretical effect due to the saving of the carbonic acid expelled. This saving was clearly shown in the present paper, and in page 600 was given a detailed explanation of the 0·63 cwt. extra of carbon transferred from the condition of carbonic acid to that of carbonic oxide, beyond the 1·30 cwt. which obviously might fairly be supposed to represent the difference between the use of limestone and of lime. He had therefore considered it his duty to explain that there was something to be done with caustic lime after all. At the same time he had to confess to its not being altogether an unmixed advantage. There were some disadvantages in working on lime; and in pages 601 and 602 he had endeavoured to point out where those disadvantages arose: namely that, although the carbonic acid of the limestone had been got rid of, and had thus been precluded from exerting any mischievous influence in the red-hot region of the furnace, nevertheless another element of mischief had been introduced in the shape of a less effective reduction of the ironstone. The carbonic acid when evolved in the red-hot region, whether resulting from the reduction of the ironstone or from the limestone, was equally damaging to the operations of the furnace, by causing the absorption of carbon in that region. Having himself found out the means by which these two mischievous influences could be separated and analysed, so as to say weight for weight what mischief was done by the one and by the other, the main object of his present paper was to indicate clearly the separation of these two items—the carbonic acid of reduction and the carbonic acid evolved from the limestone—and to point out the mischief done respectively by each.

As to any challenge (page 614) on the subject of the 23·28 cwts. of coke consumed when limestone was used and only 19·49 cwts. when working on lime (page 595), he could only say this was a matter

of fact which he could not dispute; he had found it on the face of the comparison, and had endeavoured to explain how the saving arose. The conditions under which the 23·28 cwts. of coke were being consumed when working on limestone were the same as those under which the 19·49 cwts. were being consumed when working on lime. He had endeavoured to bring these facts forward as clearly as possible, and so that there could be no possibility of questioning the conditions under which the experiments were made.

As to that perfect reduction of the ironstone, which Sir Lowthian Bell alleged (page 615) to be impossible in the upper regions of the blast-furnace, he must say that, whatever the theory evolved from the laboratory might be, perfect reduction was possible in the upper regions, and was possible only, so far as he could see at present, by the use of limestone. Thus in page 601 he had pointed out that, when working on limestone, the proportion of ironstone reduced in the cooler regions of the furnace out of contact with red-hot coke was as much as 42·49 cwts. per ton of pig-iron, whilst only 7·64 cwts. passed down into the red-hot zone for reduction there; whereas, when working on lime, the larger figure had fallen to 35·84 cwts., and the smaller had risen to 14·16 cwts. In the same page 601 he had given the reason, namely that the use of limestone absolutely created an amplified reducing region, owing to the largely increased weight of carbonic oxide per ton of pig-iron, which was obtained from the carbonic acid of the limestone and was operating in favour of a more effective reduction of the ironstone. Hence when working on lime the furnace was robbed of so much carbonic oxide in the reducing region, occasioning thereby a loss in the reduction of the ironstone in the cool region of reduction. On the other hand the previous expulsion of the carbonic acid from the flux outweighed favourably the disadvantage in reducing the ironstone less efficiently: so that on the whole the furnace could carry an extra burden, and produce an increased output of iron with an economy of coke, at the same rate of driving. He claimed only to have pointed out the exact limits where the furnace lost in the one case and gained in the other. The use of limestone was not an unmixed good, and it was not an unmixed evil. It conferred some

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benefits; but when the balance of benefits and evils was taken, it was in favour of the use of lime to the extent which he had shown. If only the mischief due to the diminished weight of carbonic oxide when working on lime could have been avoided, the economy of coke would have been more than 3·75 cwts. per ton of pig-iron; it ought to have been nearer 5 cwts. than 3·75 cwts., had he succeeded in the best anticipations held forth in his former paper in 1883. In his present paper he had sought to show wherein he had failed and how far, and also to show the extent to which he had succeeded.

In regard to the dissociation of carbonic oxide in the presence of spongy iron at a high temperature, to which Sir Lowthian Bell had referred (page 615), he had always had his eye upon this, being indebted to Sir Lowthian for having pointed out the danger of such dissociation in the upper part of the furnace; and he had himself absolutely ascertained when it was most likely to occur. The experiments he had made were free he believed from any dissociation whatever of carbonic oxide, due to the presence of spongy iron. The observations made daily and twice a day had simply been rejected whenever the furnace was working irregularly and when the dissociation took place. It had puzzled him for a couple of years before he could identify Sir Lowthian Bell's laboratory experiments with his own blast-furnace experiments; and having regarded as due to dissociation of carbonic oxide a higher ratio of carbonic acid to carbonic oxide than what could be due to normal work, he had taken no notice of the week's or month's observations while the furnace was working in such an abnormal condition. He was indebted to Sir Lowthian Bell for having pointed out that dissociation; and to his own observations for having discovered how it could be seen in the blast-furnace. Moreover in reference to Sir Lowthian's Table 5, page 616, given in confirmation of his theory that dissociation of carbonic oxide took place as far down as 68 feet depth, he would venture to suggest that the true source of the slightly increased quantity there shown of carbon and oxygen in the gases was to be found—either in the carbonic acid contained within the core of a piece of limestone, from

which it was unexpelled until it reached that great depth; or in the unreduced core of a piece of imperfectly calcined ironstone, containing both oxygen and carbon; or finally, so far as oxygen was concerned, in the unexpelled oxygen from the refractory core of a fused mass of ironstone.

With regard to the coke burned in the cupola (page 618), he had recalled on a previous occasion (Proceedings 1883, page 135) the simple law to which attention had been directed several years ago in the journal *Iron* (5 January 1883, page 19): namely that at a temperature of about 2300° Fahr. or between 1200° and 1300° centig. carbonic acid could not exist; it was dissociated instantly into carbonic oxide and oxygen. Hence his starting proposition was that the whole of the coke in the blast-furnace was immediately burned into carbonic oxide, because carbonic acid could not exist there. The conditions of a cupola were precisely the same; carbonic acid could not exist at the temperature at which it was necessary to melt the iron and slag coming down in a cupola. What was seen any evening in the dusk in the beautiful blue flame at the top of a cupola was carbonic oxide given off free, and there burning into carbonic acid. It could be seen on a frosty night in an ordinary coal fire in the house: the carbonic oxide was creeping away from the coals, and had to rise two or three inches above them before it became cool enough to burn further into carbonic acid. The carbonic acid could not be formed until the carbonic oxide was sufficiently cooled down to unite with oxygen. It was the same in the cupola and in the blast-furnace, in which the carbonic acid was dissociated because at that temperature it could not exist as carbonic acid; there could be nothing but carbonic oxide in those hot regions. Hence he had made no experiments on this point, believing that in regular work foundry cupolas could be found to melt 1 ton of pig-iron with 1 cwt. of coke, exclusive of filling in. The blast-furnace ought to melt iron with 1 cwt. to 1·1 cwt., according to the quality of the coke.

On the subject of the difference (page 615) in the working of the same blast-furnace on limestone with the moderate consumption in

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May 1882 of 21·45 cwts. of coke per ton of pig-iron (Proceedings 1883, page 119), as compared with the 23·28 cwts. given in the present paper for the same furnace still working on limestone, he would refer to the respective analyses of the working of the furnace at the former and the later period; and would call attention to the fact that in the former only 2·00 cwts. of carbon suffered transfer from the condition of carbonic acid to that of carbonic oxide, against 2·44 cwts. in the later period. The carbon absorbed by the carbonic acid of the flux was in 1882 only 1·33 cwt. instead of 1·52 cwt., owing to an increased consumption of limestone in the latter case. The slag in 1882 absorbed only 6·67 cwts. against 7·11 cwts. latterly. All this was due mainly to a change in the character of the ironstone employed, and its greater richness in iron in 1882. No greater confirmation could be found of the views advanced in the present paper than the following working out of the above figures, bearing in mind that every unit of carbon once existing as carbonic acid and afterwards re-converted into carbonic oxide (page 592) represented a total loss to the furnace efficiency of 2·26 units of carbon burnt into carbonic oxide:—$\{(2\cdot44 - 2\cdot00) + (1\cdot52 - 1\cdot33)\} \times 2\cdot26 = 1\cdot42$ cwts.; and $1\cdot42 + 7\cdot11 - 6\cdot67 = 1\cdot86$ cwts. thus accounted for as the difference between the former and the later working. The actual difference to which Sir Lowthian Bell had drawn attention (page 615) was $23\cdot28 - 21\cdot45 = 1\cdot83$ cwts., which was due solely to the inferior ironstone employed at the later period. Thus the later extra consumption of coke was fully accounted for.

In Mr. Windsor Richards's observations (page 619) he found one confirmation of his own results, and he was pleased to seize it and call attention to it: namely that he admitted an increased make from 6,505 to 7,220 tons of pig-iron per fortnight, which was an increase of 11 per cent. All that he had himself claimed in his paper (page 603) was 14 per cent. The failure to accomplish at Eston, in proportion to the quantity of flux employed, a saving of fuel corresponding with that which he had realised at Ormesby, might be owing to the fact that the matter was one requiring the greatest care and long trial; and he had no doubt further experience

would result in an economy of fuel proportional to the quantity of limestone employed in a calcined state.

Sir Lowthian Bell asked whether there was anything peculiar in the mode of introducing the calcined ironstone into the furnace. Also did the author agree that the $330 \times 20 = 6,600$ calories for melting a ton of pig-iron should be divided by the total heating power of the coke, instead of by 2,473 only, which was little more than one-third of the total heat-units in coke? And similarly in regard to the melting of the slag?

The President replied that the ironstone had been dealt with throughout the paper as already calcined when charged into the blast-furnace, according to the regular practice.

The practical heating power to be assigned to the coke for melting the iron and slag was the old vexed question on which he had differed from Sir Lowthian Bell from the outset. In Sir Lowthian's practice, as was evident from going through his papers, if a certain quantity of carbonic acid was developed and a certain quantity of carbonic oxide, he had taken the sum of the units of heat developed by the evolution of carbonic acid and by the evolution of carbonic oxide, and had divided it by the total quantity of coke burnt, and had regarded the quotient as the average number of units of heat to be accounted for in the blast-furnace. In his own practice however the very first thing that he had set himself to do had been to cast off the idea that any such average should be adopted; for he fancied that he saw that beneath any such average would be buried all the means of ascertaining what was at present behind the veil. Having then cast off that idea, what he had immediately made up his mind to do was this: the blast-furnace managers did not deal much with units of heat, but they could see and know the value of each cwt. of coke used to smelt one ton of iron in a blast-furnace; and if there was any economy possible, they would take care to seize it. Therefore, knowing that 2,473 units of heat were developed by the combustion of carbon into carbonic oxide, and that all fuel reaching the tuyeres

(The President.)
was there burnt into carbonic oxide, he had adopted carbonic oxide as the sole basis for calculation. In thus abandoning Sir Lowthian Bell's plan of averaging the heat-units according to the amount of carbonic acid and carbonic oxide conjointly, he had had to persuade himself against Sir Lowthian's conviction to the contrary; and the present paper was the outcome of the efforts he had made in this direction.

Taking furnace D, which Sir Lowthian Bell had quoted (page 614) from Table 4 in condemnation of the method of calculation followed in the paper, and accepting his total of 90,057 calories as correct, the division of this number by the standard of 2,473 heat-units, developed by the combustion of carbon into carbonic oxide, would give the total result of 36·42 cwts. of carbon consumed per ton of pig-iron, instead of the actual consumption stated in the table of only 21·24 cwts. of coke. The 36·42 cwts. of carbon would have been the consumption, had no heat been carried in by the blast, and had no carbonic oxide been burnt in the furnace into carbonic acid with its consequent extra development of heat. But Table 4 showed that 94 cwts. of air were carried into furnace D at a temperature of 695° centig., which would represent $94 \times 695 \times 0 \cdot 239 \div 2{,}473 =$ 6·31 cwts. of carbon burnt into carbonic oxide. It had further been shown in the paper (page 592) that every cwt. of carbon burnt from carbonic oxide into carbonic acid must save 1·26 cwt. of carbon burnt into carbonic oxide at the tuyeres; and assuming perfect reduction of the ironstone to have taken place in furnace D, 6·04 cwts. of carbon (page 593) would exist as carbonic acid: so that the economy at the tuyeres would be $6 \cdot 04 \times 1 \cdot 26 = 7 \cdot 61$ cwts. of carbon burnt into carbonic oxide. Hence the heat carried in by the blast and that developed by combustion of carbonic oxide into carbonic acid would be together equivalent to $6 \cdot 31 + 7 \cdot 61 =$ 13·92 cwts. of carbon; and allowing 10 per cent. for ash in the coke, there would be $13 \cdot 92 \times 100 \div 90 = 15 \cdot 47$ cwts. of coke to be added to the actual consumption of 21·24 cwts. of coke, making the total of 36·71 cwts. of coke. This result was in fair agreement with the 36·42 cwts. of carbon, or $36 \cdot 42 \times 100 \div 90 = 40 \cdot 47$ cwts. of coke, which he had calculated from the total of 90,057

calories given in Table 4. A more exact comparison could not be made unless all the conditions of working in furnace D were known.

In regard to Sir Lowthian Bell's doubt (page 615) about the possibility of obtaining perfect reduction of the ironstone, he would direct attention to Professor Grüner's observation* upon the second example of Sir Lowthian's own practice at the Clarence Iron Works, wherein M. Grüner found that not only was that furnace reducing perfectly all the ironstone, but that the total carbon absorbed in converting carbonic acid back into carbonic oxide was actually less than existed in the limestone, which proved that the whole carbonic acid of the limestone was not necessarily converted into carbonic oxide in the furnace. It was to this slight excess of carbonic acid that he had made reference in page 594 of the paper as a trifling wave of carbonic acid removed from the limestone before it reached the region of red-hot coke; and he repeated that on several occasions he had observed a like condition in the blast-furnace practice at Ormesby, whilst from the nature of the circumstances it was impossible that dissociation of carbonic oxide could have entered prejudicially into the case.

Mr. Joseph Tomlinson, Vice-President, occupying the chair during the discussion upon the President's paper, had no doubt the Members would gladly join with him in cordially thanking the President for his paper, and also in thanking Sir Lowthian Bell for his remarks respecting it. The question from its very nature was a vexed one, as to what went on inside a blast-furnace of 80 feet height when it was in full work. Therefore some diversity of opinion must be expected; and without such discussions as that which had just taken place, the degree of perfection which had now been attained in blast-furnace working could not have been arrived at. He feared the President and Sir Lowthian Bell would not be able to avail themselves of Mr. Windsor Richards's offer (page 620) to allow them

* Grüner's Studies of Blast-Furnace Phenomena; Gordon's translation (1873), § 17, page 44, foot-note.

(Mr. Joseph Tomlinson.)

to experiment on the blast-furnaces at Low Moor, because whether open-topped or closed they did not work with hot blast, and therefore the circumstances were widely different from those of the Cleveland blast-furnaces.

DESCRIPTION OF A ROTARY MACHINE FOR MAKING BLOCK-BOTTOMED PAPER BAGS.

By Mr. JOB DUERDEN, of Burnley.
Communicated through Mr. HENRY CHAPMAN.

During the past twenty years, and perhaps more particularly in the last two, rapid strides have been made in bringing the industry of Paper Bag Making to the high state of excellence it has attained, especially in Great Britain and the United States of America. Previously bag-making was carried on by hand, almost identically in the manner followed centuries ago; and it is astonishing to find that, almost without exception, this primitive method still prevails throughout the whole of the European continent.

Bag-making by Hand.—The paper having been cut to the particular size and shape required is sent to the bag-maker, who folds it with the aid of blocks; after which it is passed on to be pasted, and then to be dried. The highest rate at which the bags can be so produced is about 300 per hour, as compared with an average of 7,000 per hour by the machine about to be described.

Although the improvement of the bag machine has exercised the mechanical skill of many celebrated men, yet until quite recently the essential qualifications have not been realised which such a machine ought to possess in order to become universally applicable: namely economical production, and small cost of construction, together with a simplicity not beyond the intelligence of the child who has to attend to its working. Numerous machines are in existence, most of which deserve commendation for their simplicity and high productive power; but none of them it is believed have been capable of making on the rotary principle bags of different widths and lengths on the same machine; a separate machine has been required for every size made, and not infrequently more than one machine for making

the same size of bag, but of a different quality of paper. When it is considered that from twenty to thirty different sizes, and perhaps not less than the same number of varieties in quality of paper, are turned out in a mill of ordinary capacity, it will be readily seen that the original outlay necessary for providing all the machines required would be prohibitive of their general adoption.

Bag-making Machine.—The machine invented by the author is capable of producing bags from any description and quality of paper, no matter how soft or how stiff. The bags vary in width and length from $4 \times 5\frac{1}{2}$ to $10\frac{1}{2} \times 14\frac{1}{2}$ inches; and all sizes are made both light and heavy, thick and thin. For all these kinds, as well as for block-bottomed or oblong bags varying both in length and width, it is only necessary to have two machines, the smaller producing bags varying in width and length from $4 \times 5\frac{1}{2}$ to $6\frac{1}{2} \times 9\frac{1}{4}$ inches, and the larger from $7 \times 9\frac{1}{2}$ to $10\frac{1}{2} \times 14\frac{1}{2}$ inches. Between the foregoing dimensions any size of bag can be produced, the successive sizes varying by 1–16th inch in width and $\frac{1}{4}$ inch in length; this is an exceptional and important advantage. Undue or superfluous pressure on the sides or folds of the bags, which has hitherto been a serious and insurmountable objection, causing a tendency to split and burst when being filled with goods, is entirely obviated. The working of the machine is practically noiseless; it has a continuous feed; no folding plates or blocks are required; and the size and shape of the bag can be altered at pleasure by the boy or girl attendant by simply substituting a different change-wheel, whereby the speed of the draw-rolls is altered relatively to that of the cutter, paster, and folders. The machine being on the rotary principle, the wear and tear of its parts are reduced to a minimum. A space of 15 feet by $4\frac{1}{2}$ feet is all that is required, including the drying cylinder; less than $\frac{1}{4}$ HP. is sufficient to drive the machine, and either gas or steam may be used for this purpose. All these are necessary requirements for a good, cheap, economical, and thoroughly efficient machine; the most important are speed and efficiency. The speed already mentioned of 7,000 bags per hour means say 120

per minute, or two per second, dry and ready for immediate use. The specimens of bags exhibited testify to the efficiency of the machine.

Description of Machine.—A horizontal roll of paper, of a width suitable for the size of bag required, is carried on bearings in the position shown at A in the elevation and plan, Figs. 1 and 2, Plates 114 and 115. As the paper is drawn forward, paste is applied to the margin, in the exact position required and with suitable pressure, by the adjustable paster-wheel B. In its further traverse, the paper passes over the longitudinal central tube-former C, which is less than half the width of the paper; the overhanging edges of the web of paper consequently droop on each side, and thus cause the flat band of paper to assume an inverted trough-like form, which is gradually closed in underneath the tube-former to the shape shown in the transverse section, Fig. 4, Plate 116, by means of side fingers and guide brackets in connection with the central tube-former C. While in this position a semi-circular cut is made by a cutter T, Figs. 1 and 2, to form a lip or thumb-piece at the front end of each bag, Fig. 5, Plate 117, which end is afterwards folded over to form the bottom of the bag; while the corresponding notch at the back end is useful for readily finding the opening or mouth of the bag. When the paper reaches the first pair of draw-rolls D, Fig. 3, it has assumed the necessary tubular shape in its passage over the tube-former C; the dry margin is here closed over the pasted margin and pressed between the rolls D, securing the longitudinal seam of the bag. On arriving at the severing rolls E, it first passes free between them, without being as yet severed into the length required.

The tucker-blade M sliding in curved slots, in conjunction with the tucker or inclined finger N, Fig. 3, Plate 116, for the formation of the first or diamond fold, Fig. 6, is so arranged that the edges of the paper at the centre of the fold may be drawn more closely together to produce a square bottom. The tube of paper is supported, from the first draw-rolls D to the tucker N, by a

longitudinal reciprocating distending-rod G, the fore end of which, being fitted with a pair of flat springs expanding outwards, as shown in Fig. 3, causes the forward end of the tube to gape open for the reception of the tucker N.

The tucker having laid and carried the diamond fold to the bite of the second pair of draw-rolls F, Fig. 3, Plate 116, the paper tube is now immediately severed by the pair of severing rolls E. At the same time paste is being applied to the central portion of the primary diamond-shaped fold by a segmental paster-block I, Fig. 10, Plate 117, fixed upon the shaft of the upper roll F; the paster-block I is situated centrally between the two loose sections composing the top roll of the second pair of rolls F, which are driven at the same surface speed as the first pair of draw-rolls D. The paste is applied to the diamond fold along the lines *a a* shown in Fig. 6. The segmental paster-block I receives paste from a paste trough H through the medium of a feed roller R communicating directly with the interior of the trough, into which it protrudes; the supply of paste is regulated by a slide plate at the bottom of the trough, by adjusting the plate as required nearer to or further from the roller.

The length of the bag is determined by the increased or diminished speed of the two pairs of draw-rolls D and F in excess of that of the severing rolls E. The speed of the latter may be increased or diminished immediately before or during the severance of the bag from the paper tube, in accordance with the speed of traverse of the tube. For this purpose, two discs K and L are secured upon two separate shafts, Figs. 11 to 14, Plate 117, one disc L being provided with a slot in which a pin on the other disc K is capable of working in such a manner that, when the centre of one shaft is lowered beyond the other, a variable motion will be transmitted to the slotted disc L, which is secured to the severing rolls E and actuates them accordingly in each revolution at a varying speed, quickest at the moment of severing the bag. The segmental paster-block I and the pair of severing rolls E complete one revolution for one bag, whatever its length. As already stated the length is determined by the surface speed of the two pairs of draw-rolls, and this speed is increased or diminished by the

substitution of a change-wheel of larger or smaller diameter, as may be required for the length of the bag to be made.

To complete the formation of the bag, the two cross-folds or V shaped overlaps of the bottom are yet to be laid. These are now creased or laid by two folding blades, each acting between the nip of two rolls, Fig. 3, Plate 116; the folder P and roller U form the first bottom fold, as shown in Fig. 7, Plate 117; the second bottom fold is formed by the folder Q and roller V, as shown in Fig. 8, which is done by folding over also the bag itself bodily, thereby forming a blank or blind fold in the body of the bag. On leaving the roller V, this blank fold of the bag partially springs open; it is therefore fully opened and finally flattened out whilst the bag is being conveyed by the travelling felt W from the machine to the drying cylinder, as shown in Figs. 1 and 2, Plates 114 and 115, and more completely in Figs. 15 and 16, Plate 118. The bag has then assumed the shape shown in Fig. 9, Plate 117, with both angular overlaps cemented by the paste to the body or primary fold of the bag.

As the whole of the various operations of pasting, cutting, and folding, are effected during the uninterrupted continuous traverse of the paper through the machine, a very considerable increase is thereby realised in the number of paper bags manufactured per hour, with the additional advantages of economy in working and in cost of construction of the machine.

Discussion.

The President said the author of the paper was unable to be present, being still in Paris with one of these bag-making machines at work in the Exhibition, where many of the Members had had the opportunity of witnessing its working at the time of the recent Summer Meeting there. In his absence however, the makers and proprietors of the machines, Messrs. Bibby and Baron, of Burnley, were represented by Mr. Bibby, and by Mr. Pearson of Messrs. Pearson Richmond and Co., Burnley.

Mr. James T. Pearson exhibited an extensive collection of the bags made by the machine, ranging from $4 \times 5\frac{1}{2}$ to $10\frac{1}{2} \times 14\frac{1}{2}$ inches in width and length, and made of various qualities of paper, thick and thin, strong and tender, coarse and fine. He showed also a complete series of progressive specimens stopped at the successive stages of the process, so as to illustrate the exact operation performed by the machine at each stage in the continuous progress of the work, during the gradual transformation of the original flat band of paper into the finished block-bottomed bag with all the folds completed and pasted.

Mr. Henry Chapman said all the facts announced in the paper could be proved; and any one who had seen the machine at work in the Paris Exhibition must have remarked how easily it was attended to by a young girl. The machine itself had obtained a gold medal, notwithstanding that there had been competitors, both French and American exhibitors, who only got silver medals; and a silver medal had also been given to the inventor as a special mark of approbation. It was certainly considered to be the best bag-making machine ever exhibited, and he might safely say that it was the best one known at the present day.

The President asked if he had seen the machine running at 7,000 bags an hour.

Mr. Chapman replied that he had seen it running at a speed of 140 bags per minute, which would be at the rate of 8,400 an hour; but the real commercial speed was about 120 bags per minute. For his own satisfaction he had had the machine run up to 140 bags per minute; and at that speed its working was as satisfactory in all respects as at the regular commercial speed of 120 per minute, or 7,200 per hour.

Mr. Jeremiah Head, Past-President, asked whether the paper used was of any particular sort. Thirty or forty years ago paper had generally been made of rags; but since those days it had come to be made of grass, of straw, and even of wood. He had been trying by hand some of the specimen bags shown, and he found that they were very strong. The paper on which some newspapers were now printed would scarcely bear any tension whatever by hand. In the case of the bags exhibited, the edges were wetted with paste at some parts of their travel; and it would seem as if there must be a considerable amount of fibre in the paper to stand both dry and wet the operation of manufacture into bags by the machine, and also to stand the pressure of the goods in the finished bags afterwards.

Mr. Edward B. Marten, Member of Council, asked whether the cut at the ends of the bags, for severing them from the continuous band of paper, was purposely notched along the edge; and what was the object of the edge being notched. Did the travel of the bag stop while it was being cut across, or was it a continuous motion throughout without any pause?

Mr. Chapman replied that the travel of the bag was continuous without any pause. The notched edges where the bags were severed across were purposely made so by a serrated cutter in the upper roll of the pair of severing rolls; the serrated cutter coming into operation at the right moment in the revolution pierced through the paper first at the points of the serrations, and then cut through it along the inclined lines to the bottoms of the notches; and as the severing rolls were running in that part of their revolution at a slightly

(Mr. Henry Chapman.)
higher speed than the draw-rolls, the paper was immediately torn asunder across its entire width by the pull of the cutter upon the paper, which was not running at that moment quite so quick as the severing rolls.

Professor Alexander B. W. Kennedy, Member of Council, hoped it would not be thought that the value of the paper was to be estimated in proportion to the amount of discussion upon it. The Members of the Institution he was sure would agree in considering that it was a paper of a highly valuable character; and they did not show their respect for it the less because they did not attempt to discuss a machine of so special a kind, which was seen by the work it turned out to be so admirably contrived for the purpose intended.

Mr. Perry F. Nursey said one of the bags which he had just examined was made of a decidedly inferior quality of paper. It was so soft that he should think it would get much damaged in the machine if the action throughout were not very perfect.

Mr. Arthur Paget, Vice-President, had also found among the specimens exhibited bags made of paper which was so easily torn that it seemed difficult to handle them at all without risk of tearing them. What had struck him as the most ingenious of the many ingenious contrivances in the machine was the method of turning over the last fold for completing the closing of the bottom of the bag, as this fold could not be folded up from behind. The only doubt that occurred to him was whether there might be an occasional failure in the blank fold to open out again as it was required to do after passing the last roller. He asked whether a peculiarly quickly acting quality of paste was required for ensuring that the last flap should always stick, without liability to miss being brought back again with the blank fold when the latter was opened out; and whether any special means were provided for ensuring that the blank fold itself should always be brought back again and opened out. The plan was most ingenious; and if it did not require special paste,

and was not liable to failure, he thought it was worthy of all praise.

Mr. James T. Pearson said that various descriptions of paper made in England were made from rags; and paper was also made from wood pulp, which gave it a very stiff quality. The bag machine was capable of making bags from all the various kinds of paper. As to the thinnest quality, if the paper would hold goods at all after the bag had been made, the bag machine would make it. The serrated edge of the paper was made by a knife which of course had itself a serrated cutting edge, and it was found that this was the best means of severing the paper; that was the only reason for the edges being serrated. The thumb-notch was to facilitate opening the mouth of the bag; on placing the thumb in the notch and waving the bag briskly in the air, the mouth of the bag would open itself at once. The blank or blind fold was opened out and drawn back into its proper position while the bag was being conveyed by the travelling bands to the drying cylinder.

Mr. John T. Bibby further explained that, after the blind fold had been made, the bag dropped from the roller V, Fig. 16, Plate 118, and fell upon a travelling felt W, which carried it forwards to the drying cylinder. In dropping upon the felt from the roller V, the bag fell bottom foremost and with the blind fold uppermost: so that the blind fold was free to recover itself and open out again to about a right-angle from the body of the bag; while the paste being pretty strong was just able to hold down the last bottom fold, for the sake of which the blind fold had been made. Above the felt was a pair of inclined strings S, sloping downwards towards the felt W, and running in the same direction, but just a little quicker: so that, as soon as ever the partly opened blind fold touched the strings, it was gradually pulled over and fully opened out flat upon the felt by the quicker speed of the strings. This plan answered so well that practically the blind fold never missed being opened out flat in the regular working of the machine. In the works of his firm it was customary to run the machine at from 120 to 150 bags

(Mr. John T. Bibby.)

per minute. Whenever any visitors had come to look at it and had counted the number, they had always found it was going at a higher rate than that stated in the paper.

In the severing of the bags the cutting was continuous along the zigzag line of severance, in consequence of the knife being serrated along its cutting edge. If made with a straight plain edge, the knife would not be able to cut through the paper all at once: but with a serrated edge it cut through it more gradually, at the points of the serrations first and afterwards through the rest of the zigzag.

One of the most ingenious things about the machine was the segmental paster-block, shown at I in Fig. 10, Plate 117. The two outside rollers, forming together the top roller of the second pair of draw-rolls F, ran loose on the same shaft on which the paster-block I was fixed between them; but if the paster-block ran at the same speed as the outside rollers, it would simply make a mess of the bag by pasting too great a length of it, because the outside rollers had to run more than once round for each bag; the paster-block always ran exactly once round for each bag, while the outside rollers had to run faster, and at different speeds for the different lengths of bags. This necessitated the peculiar construction shown in Fig. 10, with the shaft so arranged that the outside rollers ran loose upon it. The paste used was ordinary paste, made only of flour and water.

The President fully concurred in the opinion expressed by Professor Kennedy, that, although the paper was not one which was open to much discussion, yet its merits would be appreciated none the less by the Members, because it appealed so simply to their sense of what was suitable for a machine that was required to be quick and efficient in its action. They would all join with him he was sure in a hearty vote of thanks to Mr. Duerden for his paper, and to Mr. Pearson and Mr. Bibby for the capital collection of specimens by which it was so completely illustrated.

FURTHER EXPERIMENTS ON CONDENSATION AND RE-EVAPORATION OF STEAM IN A JACKETED CYLINDER.

By Major THOMAS ENGLISH, R.E.,
Superintendent, Royal Carriage Department, Woolwich.

The author has recently been able to utilize a series of trials, made in the Royal Carriage Department at Woolwich Arsenal, in an attempt to ascertain the amount of Initial Condensation and subsequent Re-evaporation of Steam in a jacketed Cylinder; and he has now the pleasure of laying the results before the Institution in continuation of his paper on the same subject read in September 1887 (Proceedings page 503).

The engine with which the trials were made is a double-cylinder one of 16 nominal horse-power, made by Messrs. Marshall Sons and Co. of Gainsborough, and is used in the Royal Carriage Department for factory purposes, and occasionally for electric lighting. The cylinders are horizontal and attached to a wrought-iron framing underneath the boiler, each being 10 inches diameter and 14 inches stroke; the piston-rods of 1·6 inch diameter pass through one end only, and are connected to a double-throw crank-shaft with a fly-wheel 5½ feet diameter on one end. The power is taken by means of a belt from a pulley 4 ft. 2 ins. diameter on the other end of the crank-shaft. The main slide-valves are of ordinary pattern, flat-faced, double-ported, with 0·7 inch outside lap, 0·125 inch inside lap, and 2·6 inches travel; the angular advance of the main eccentrics is 30°. Flat-faced expansion-valves with no lap work on the back of the main valves, over ports measuring 8·625 inches by 0·625 inch; and the cut-off is automatically regulated by the action of a governor lifting at about 206 revolutions per minute, and shifting the expansion-valve connecting-rod in a slotted

lever, which works on a fixed pin at one end, and is actuated at the other by an eccentric set at 131° angular advance with 2·75 inches throw.

The mean clearance volume in each cylinder is 0·051 cub. ft., or 0·081 of the volume swept through per stroke, which is 0·628 cub. ft. The clearance surface is 2·30 sq. ft., and the surface exposed during the stroke is 3·05 sq. ft.

The load on the engine during the experiments consisted of one Brush dynamo, running light at about 680 revolutions per minute, and one Crompton dynamo running at 825 revolutions per minute, and driving from three to fifteen arc-lamps, with a potential of 165 volts and a current of 110 ampères under the full load, the engine running at about 120 revolutions per minute. Indicator diagrams were taken from each end of each cylinder, with two Richards indicators having springs of 48 lbs. per inch, and two Crosby indicators having springs of 50 lbs. per inch.

The cylinders themselves are liners, 0·625 inch thick, inserted in a single casting, which forms the jacket, and is supplied with steam coming direct from the boiler, separately from that used in the engine. The jacket is of about 0·35 cubic foot capacity, and is provided with a drain cock at the lowest point, from which the condensed water was collected by means of a steam trap. About 7·3 square feet of the exterior surfaces of the two cylinders are exposed to the jacket steam.

The boiler is of locomotive type, with a grate area of 10·5 square feet; the firebox is of iron, measuring 3 ft. 0 in. by 3 ft. 4 ins. by 3 ft. 2 ins. deep to the bars. The heating surface is 285 sq. ft., including the firebox above the bars, and fifty iron tubes, 2·5 inches outside diameter and 7 ft. 10 ins. long. The surface covered with non-conducting material is 118 sq. ft., and the uncovered surface of the firebox is 44 sq. ft. The boiler is ordinarily lagged with wood covered with sheet iron; but the wood was removed during the progress of the trials, and various other non-conducting materials were substituted for it, the primary object of the experiments being to determine the relative values of these. The average evaporation per lb. of Barnsley hard steam coal was 8·43 lbs. of water from and

at 212° Fahr., the rate of combustion with full load being about 14·2 lbs. per square foot of grate per hour. The feed pump, consisting of a single-acting plunger 3 inches diameter and 3·375 inches stroke, was driven continuously by the engine, the excess of water not required for the feed being returned to the feed tank. Steam for the blast, when required, was obtained from an adjacent boiler.

The steam passing through the engine was led through an exhaust pipe 4 inches diameter and 17 feet long, to the same surface-condenser which was used in the author's previous experiments. The details of this condenser, which was worked by a separate boiler, are given in his former paper (Proceedings 1887 page 479), and it is therefore unnecessary to repeat them here.

In order to measure as accurately as practicable the quantity of feed-water used, it was determined to weigh both the feed-water into the boiler, and also the condensed water after passing through the engine. For this purpose, the feed tank, containing about 200 gallons, was mounted on a weighing machine, and filled by a hose; the collecting tank from the condenser, also holding about 200 gallons, was similarly mounted on a weighing machine; and small supplementary tanks were provided, into which the feed suction pipe and condensed-water collecting pipe could be diverted, whilst the main tanks were being refilled or emptied respectively during a trial.

As the object of the trials was twofold—firstly to ascertain the weight of water evaporated per pound of coal, and secondly to ascertain the weight of water used per stroke of the engine—the following method was adopted. Steam having been raised to the required pressure, the engine was run with the load on, and the fire was allowed to burn down until as little as possible remained in the grate, and the steam pressure began to drop; firing was then commenced with weighed coal, and the weights of water in the feed tank and in the collecting tank were noted. When the fire had been got into a proper condition for maintaining a steady pressure of steam, a counter was connected, and the weights of tanks were again noted.

The counter was disconnected after a previously arranged number of minutes had elapsed, and the weights of the tanks were noted; the difference between these and the weights at the commencement was taken as the weight of water used during the number of revolutions indicated by the counter. The running of the engine was continued until the steam pressure again began to drop, and the fire had got as nearly as practicable into the same condition as at the commencement; the weight of coal used was then noted. The weights of the tanks were also noted at this time, and the difference from the weight at the commencement of firing with weighed coal was taken as the weight of water evaporated during the trial. Any calculated amount due to difference of height in the gauge glass was added to or subtracted from the weight of the feed tank, as required. The result of this double system of weighing has certainly been to confirm the opinion expressed by the author in his previous paper, that the weight of water used can be obtained more accurately from a collecting tank than from a feed tank; and the weights employed in the calculations are those obtained from the collecting tank, with one exception, No. 26, when a leakage through the condenser was detected. (See appended Tables 9 and 10, pages 658–669.)

Indicator diagrams were taken as frequently as practicable, not less than sixteen during any one trial; and the indicator springs have been subsequently tested and found correct. Fifty-five trials in all were made, out of which the first eight, and five of the remainder were rejected for doubtful measurements, leaving forty-two of which the results are here recorded (Plates 119 to 127); the duration of each trial was between one and six hours. The tightness of the condenser was tested in every trial, and the engine was maintained in good running order throughout.

In certain of the trials, Nos. 30 to 35 and 37 to 39, an auxiliary slide-valve was fitted, communicating with each end of each cylinder by pipes furnished with a stop cock, by means of which a graduated amount of atmospheric air was admitted to the cylinder during the exhaust, and was compressed together with the steam, the object being to ascertain whether the initial condensation could be reduced by this means. This proved to be the case, but the resulting gain

in economy of steam consumed was almost exactly counterbalanced by the increased back-pressure.

Twenty-one of the trials were made with circulation of steam through the jacket, and twenty-one with the drain cock shut. Nos. 45 and 55 of the former and Nos. 39 and 40 of the latter, made with a very light load and consequent small consumption of steam per stroke, gave results which showed that the steam was being sensibly superheated, presumably by the heat of the smoke-box which envelopes the steam supply.

Three trials (Nos. 18, 21, and 22) with circulation through the jacket, and three (Nos. 23, 24, and 25) with the drain cock shut, were made with the air-pump of the condenser disconnected, and therefore condensing at atmospheric pressure.

The indicator diagrams from each trial were dealt with as follows. The initial pressure, the terminal pressure, and the pressures during the expansion at two intermediate points marked A and B (Plates 119 to 127), were measured on each diagram, and the average results were taken for the forward pressures at these points. All the diagrams were measured with a planimeter, to obtain the mean forward pressure; and a diagram corresponding as nearly as possible with the average result thus obtained, and not remarkable in any other way, has been selected as the mean diagram representing each trial. This has been done in preference to reconstructing the mean diagram from average measurements, as the author believes that most engineers who wish to analyse the trials would prefer an actual average diagram drawn by the engine itself, to a reconstructed one. The calculations made to obtain the observed condensation have been carried out in precisely the same way as that detailed in the author's previous paper (Proceedings 1887 page 492), and need not therefore be further described.

All the results obtained are shown in Table 9, and the mean diagram representing each trial is shown in the upper part of Plates 119 to 127. The average results of each series in which the conditions were intended to be the same are shown in Table 10, and have been obtained by taking the arithmetical means of the results in Table 9, every trial of more than one hour's duration being

regarded for this purpose as so many separate trials of one hour each. Each series of trials has been grouped under a separate roman numeral, I to XVIII; and these numerals are arranged in order of comparative efficiency. For comparison with calculation this efficiency has been taken as the proportion of work done to available heat in the steam used in the cylinder only. In Table 10 are also shown the actual efficiencies as measured by the water used per horse-power per hour, including the jacket steam collected during a trial, but disregarding that collected at the conclusion of trials made with the jacket drain-cock shut. This latter quantity is small and uncertain in its amount and effects, and on the whole it seemed best to neglect it.

The average results of observed net condensation in each series are shown in the lower diagrams in Plates 119 to 127; the total heights of these lower diagrams represent the number of thermal units of available heat supplied per stroke, which number is also given in figures, both including and excluding the jacket steam. The black dots in these lower diagrams are placed in such positions that the vertical distances measured downwards to them from the top of the lower diagram give the observed average number of thermal units of condensation, less re-evaporation, at the point of the stroke indicated: the lower line UU gives the calculated net condensation when the cylinder is unjacketed, and the upper line JJ when jacketed; these three quantities are also given in figures in Table 10. The numerical results have been checked over by two independent calculations, and generally by the use of different methods.

The general result of the observed amounts of net condensation appears to the author to be strongly confirmatory of the view advanced in his previous paper—that the initial condensation is extremely sudden, and that there is an excess of re-evaporation over condensation during the whole of the forward stroke.

Clearance Surface.—Whatever view may be taken of the nature of the process which causes condensation in a steam cylinder, it appears

to the author that the number of thermal units of heat transferred must vary directly as the area of that portion S_c of the clearance surface which is colder at the moment than the entering steam, whether the surface be that of a film of water or of the actual metal. In assigning the value of this colder portion S_c however, it is necessary to deduct from the whole clearance surface any portion which is permanently heated from the outside, as by steam-jacketing the end of the cylinder or by other means, to a temperature exceeding that of the entering steam. Such portions must remain dry throughout the whole cycle, and can produce no effect by contact either on the initial condensation or on the subsequent re-evaporation during the stroke. The effect of the cold portion of the clearance surface in producing condensation must be most marked at the first instant, when the difference of temperature is greatest; and must diminish as the surface is brought up to the same temperature as the steam in contact with it. The number of units of heat transferred at each stroke cannot therefore be assumed to vary directly as the time of exposure, or inversely as the number of revolutions in a given time; and every experiment made by the author tends to show that it varies, at any rate approximately, as the square root of the time of exposure, or as $\frac{1}{\sqrt{N}}$, where N is the number of revolutions per second. This result, as pointed out by Professor Cotterill (Proceedings 1887 page 536), is also to be expected on theoretical grounds. The effect of clearance surface will therefore be represented by the factor $\frac{S_c}{\sqrt{N}}$.

Temperature.—Next, as to the effect of temperature, it is frequently assumed that the condensation must vary directly as the range of temperature in the cylinder; but this view appears to the author to be based upon a fallacy. It is true that there is experimental evidence, obtained by Forbes and others, to show that the rate of transmission of heat through a metallic plate depends on the difference of temperature of the media on either side, and that therefore the condensation of steam, in long continued contact with metal, should vary as the difference of temperature of the two sides; but in that case there is a steady flow of heat,

and the temperature of the side of the plate in contact with the steam must be uniform, and sensibly the same as that of the steam. But the condition of things when steam is entering a cylinder appears to the author to be entirely different; the steam is brought into sudden contact with a surface sensibly colder than itself; and to say that the condensation will depend upon the range of temperature is equivalent to saying that there would be no condensation at all after the temperature of the inner surface of the cylinder is raised to that of the incoming steam, a result directly at variance with both theory and practice. It appears to the author that in a steam cylinder there will be a nearly constant rate of condensation due to conduction through the metal, and depending in amount on the mean temperature; and that to this should be added a variable rate due to the proportion borne by the range of temperature above the mean in the cylinder to the absolute mean temperature of the metal: so that, if the absolute temperature of the incoming steam be denoted by T_1, and the absolute mean temperature of the inner surface of the cylinder by T_m, the maximum rate of condensation will vary as $1 + \frac{T_1 - T_m}{T_m}$, or as $\frac{T_1}{T_m}$. Also that in cylinders which are jacketed, or in which the flow of heat to the outside is prevented by any other equivalent means, T_m will approach T_1, and the effect of range of temperature will become negligible.

Density of Steam.—Next, all the author's experiments, and all others which he has had an opportunity of analyzing, tend most conclusively to show that the initial condensation varies directly as the density of the incoming steam; and it appears to him that this result is also one which must be expected on theoretical grounds. For whatever may be the nature of the action between the steam and any given portion of the condensing surface, it cannot be sensibly affected by the precisely similar actions going on simultaneously on other portions of the surface; and whatever be the rate of condensation, whether it be the same or different on each portion, it must depend directly on the number of particles of steam brought into contact with a given area, or in other words it must vary directly as the density.

Formulæ.—The foregoing considerations have led the author to propose as the expression for initial condensation per stroke in an unjacketed cylinder

$$C_U W = A_U \frac{S_c}{\sqrt{N}} \frac{T_1}{T_m} \rho_1$$

where C_U is the initial condensation in thermal units per pound of steam in an unjacketed cylinder; W is the weight of water in pounds per stroke; S_c is the clearance surface in square feet after deducting any jacketed portion; N is the number of revolutions per second; T_1 is the initial absolute temperature of the steam; T_m is the absolute mean temperature of the cylinder, approximately equal to the temperature due to the mean forward pressure; ρ_1 is the initial density of the steam in pounds per cubic foot; and A_U is a constant, which from his own experiments and from those made in the U.S. Navy in 1874–5 the author deduces to be equal to 80 for Fahrenheit temperatures.

For jacketed cylinders of ordinary proportions, $T_m = T_1$; hence the initial condensation per stroke

$$C_J W = A_J \frac{S_c}{\sqrt{N}} \rho_1$$

where C_J is the initial condensation in thermal units per pound of steam in a jacketed cylinder. The value of the constant A_J, obtained directly from the author's experiments on initial condensation in a jacketed cylinder, where the piston was blocked at the end of the stroke, was 56; and this agrees with that deduced from the present series of experiments on the ordinary working of a jacketed engine, when it cannot be directly measured.

Applying converse reasoning to the re-evaporation which takes place during the stroke, it appears to the author that, when a metallic surface is in contact with wet steam, re-evaporation will commence immediately that the steam pressure is reduced below that due to the temperature of the metal; and that the number of thermal units transferred from the metal must vary directly as the surface exposed, and approximately as the square root of the time of exposure. Also that, under the conditions of a steam cylinder, if T_m be the absolute mean temperature of the metal, between the commencement

of the stroke and the instant considered, and T_2 the absolute temperature of the steam at the same instant, the total number of thermal units transferred will vary with $\frac{T_m}{T_2}$, and finally with ρ_m, the mean density of the steam, as this latter quantity determines the number of particles of wet steam which are brought into contact with any given area of the hot metal. As soon as the exhaust is opened, the rush of steam through the passages will probably sweep away any water remaining at the end of the stroke, and thus prevent further re-evaporation or transfer of heat from the metal during the return stroke.

It does not appear to be possible to ascertain directly the value of T_m, the mean temperature of the surface of the metal; but it evidently cannot differ much from the mean temperature of the steam; and if it is assumed equal to the latter, the expression for the total re-evaporation in unjacketed cylinders will become

$$B_U \frac{S_2}{\sqrt{N}} \frac{T_m}{T_2} \rho_m$$

where S_2 is the total surface exposed up to the point of the stroke considered; N the number of revolutions per second; T_m and ρ_m respectively the mean absolute temperature and mean density of the steam, between the commencement of the stroke and the point in question; and T_2 the actual absolute temperature of the steam at this point.

For jacketed cylinders T_m will be replaced by T_1, as the temperature of the surface of the metal will be maintained nearly at this constant amount, namely that of the incoming steam, by the supply of heat from without; and the expression will become

$$B_J \frac{S_2}{\sqrt{N}} \frac{T_1}{T_2} \rho_m.$$

Initial condensation and corresponding transfer of heat to the metal will of course go on upon each fresh surface exposed during the stroke; but the supply of heat to effect this is drawn by re-evaporation from that stored up in the surface already exposed; and the effect of the exposure of fresh surface will be, not to increase

the total amount of heat transferred, but merely to distribute it over a larger area. If then S_2 is taken to represent, not the total surface exposed, including the clearance, but only the fresh area uncovered during the stroke, the re-evaporation expressed by $B_U \frac{S_2}{\sqrt{N}} \frac{T_m}{T_2} \rho_m$ or $B_J \frac{S_2}{\sqrt{N}} \frac{T_1}{T_2} \rho_m$ will represent the excess of re-evaporation over condensation, which can be directly observed.

In the author's experiments the values of B agree with those of A already determined for initial condensation: that is $A_U = B_U = 80$ for unjacketed cylinders, and $A_J = B_J = 56$ for jacketed cylinders. This is clearly shown by the circumstance that the lines UU and JJ in the lower diagrams in Plates 119 to 127, representing the amounts of net condensation at various points in the stroke, calculated according to these values, are more or less nearly parallel with the line which would pass through the black dots representing the observed results. These calculated amounts were necessarily based on the assumption that dry saturated steam was supplied, which no doubt was not always the case; and this directly affects to the same amount both the total number of thermal units supplied during the stroke, which are represented by the total height of the diagram, and the calculated amount of condensation, which is obtained by subtraction from the total supply. It will be seen however that the difference between the observed and calculated results is approximately constant throughout the stroke; and that the calculated rate of diminution of net condensation agrees very closely with observation in every case.

Denoting the re-evaporation per pound of steam by R_U and R_J respectively for unjacketed and jacketed cylinders, the complete formulæ which the author submits to represent the net condensation in a steam cylinder at any point of the stroke will become therefore

$$(C_U - R_U)\,W = \frac{80}{\sqrt{N}}\left(S_c \frac{T_1}{T_m} \rho_1 - S_2 \frac{T_m}{T_2} \rho_m\right) \text{ for unjacketed cylinders}$$

$$(C_J - R_J)\,W = \frac{56}{\sqrt{N}}\left(S_c\, \rho_1 - S_2 \frac{T_1}{T_2} \rho_m\right) \text{ for jacketed cylinders}$$

any portion of S_c which is jacketed being deducted in either case.

These are extensions of the formulæ suggested by the author in his previous paper (Proceedings 1887, page 505), the difference being that a factor for the effect of temperature is now introduced, and that the mean density of the steam ρ_m is now substituted for the sum of a constant 0·06 added to the density ρ_b which corresponds with the back pressure. The reasons why these factors were not introduced into the original formulæ were because the experiments on which they were based did not include sufficient variations of temperature and pressure to make it apparent that any correction for varying temperatures was necessary, and because the mean density happened to agree throughout nearly with $\rho_b + 0{\cdot}06$.

Calculation of Steam used per Stroke.—The practical object of determining the amount of condensation and re-evaporation at any point of the stroke is to obtain some basis of calculation for the weight of steam used per stroke; and this may be readily effected as follows. Let X be the volume swept through, up to the point of cut-off, in cubic feet; c the ratio which the clearance volume bears to X; n the ratio of volume of cushion steam to steam discharged per stroke, at the initial pressure. Then $(1+c)\ (1-n)\ X$ is the volume in cubic feet, at initial pressure, of the mass of steam discharged per stroke; and $\rho_1\ (1+c)\ (1-n)\ X$ would be the weight of steam required to fill the cylinder per stroke, if there were no condensation, or the weight per stroke accounted for by the indicator at cut-off. At the point of cut-off $\rho_m = \rho_1$, and $T_m = T_2 = T_1$, and if the fresh surface exposed during admission be denoted by S_1 the weight of steam condensed and not evaporated per stroke at this point will be $\frac{80}{\sqrt{N}}\left(\frac{S_c - S_1}{L}\right)\rho_1$ in an unjacketed cylinder, or $\frac{56}{\sqrt{N}}\left(\frac{S_c - S_1}{L}\right)\rho_1$ in a jacketed cylinder, where L is the latent heat of evaporation. The total weight W per stroke is the sum of the weights thus found; or

$$W = \left(\frac{80}{\sqrt{N}}\ \frac{S_c - S_1}{L} + (1+c)\ (1-n)\ X\right)\rho_1 \quad \text{for unjacketed cylinders.}$$

$$W = \left(\frac{56}{\sqrt{N}}\ \frac{S_c - S_1}{L} + (1 + c)\ (1 - n)\ X\right) \rho_1 \quad \text{for jacketed cylinders.}$$

If x_2 be the percentage of steam in the working mixture at any point of the stroke, and v_2 the volume of one pound of saturated steam of pressure p_2 at the same point, it is further possible after having determined W, to obtain approximately the value $v_2\ x_2$ of the volume occupied by a pound of steam in the cylinder, at any consecutive values of the pressure p_2 which may be chosen during the expansion, and thus to draw an approximate expansion curve, and complete the calculated diagram. To do this we have the equations

$$Q_2\ W = \left(\frac{p_2\ v_2}{5{\cdot}36\ (1 + c)\ (1 - n)} + I_2 - h_2\right) W\ x_2 + h_2\ W$$

$$Q_2\ W = Q_1\ W - \frac{80}{\sqrt{N}} \left(S_c\ \frac{T_1}{T_m}\ \rho_1 - S_2\ \frac{T_m}{T_2}\ \rho_m\right) \quad \text{for unjacketed cylinders}$$

$$Q_2\ W = Q_1\ W - \frac{56}{\sqrt{N}} \left(S_c\ \rho_1 - S_2\ \frac{T_1}{T_2}\ \rho_m\right) \quad \text{for jacketed cylinders}$$

where Q_1 is the total heat supplied per pound of steam; Q_2 the heat remaining in a pound of mixed steam and water at any point of the stroke; I_2 the internal heat of a pound of steam at pressure p_2; and h_2 the heat contained in a pound of water at the temperature corresponding to p_2.

The value of ρ_m is required to solve these equations, and this may be obtained by calculating the mean pressure P_m approximately step by step on the curve—on the assumption that between any two nearly adjacent points the expansion curve is a straight line—by the equation

$$P_{m2} = \left(P_{m1} - \frac{p_1 + p_2}{2}\right) \frac{v_1\ x_1}{v_2\ x_2} + \frac{p_1 + p_2}{2}$$

starting from the point of cut-off, where $P_{m1} = p_1$. A further assumption of the approximate values of c and n at each point on the expansion curve is necessary to solve the equations; these values however vary but slowly. But the calculations are tedious, and in

the author's opinion for practical purposes it is necessary to determine only the weight of steam used per stroke, and then to draw an expansion curve, either hyperbolic or according to whatever law may be considered most appropriate to the circumstances of the case. In any further calculations of efficiency the error involved by this method does not extend beyond the ratio borne by the difference of area between the curve thus drawn and the real one, to the total area of the diagram.

It will be observed that the author has adhered throughout the calculations in the present paper to Professor Cotterill's method of separating the steam discharged per stroke from the cushion steam, in preference to the method advocated by Mr. Longridge in the discussion on the previous paper (Proceedings 1887, pages 511–516), of determining the total heat present in the cylinder at the various points of the stroke. Both methods give practically identical results; the only difference, even theoretically, is that in Professor Cotterill's a hyperbola is taken for the compression curve, instead of that drawn by the engine. But the author considers that the method which he has followed is by far the most convenient for the calculations involved.

The weights of water per stroke, resulting from calculations made from the same data as those of the author's experiments, are given in Table 10 and Plate 128, for comparison with the observed weights. In the experiments made with the jacket drain-cock shut, the effect of the jacket is evidently reduced by an uncertain amount, and the calculated weights are given both for jacketed and unjacketed cylinders. The number of thermal units of initial condensation calculated by the author's formulæ, and of net condensation at the end of the stroke, and at the two intermediate points A and B, are also given in Table 10; and a fair line drawn through these four points in each case is shown on each of the lower diagrams in Plates 119 to 127, from which the calculated net condensation at intermediate points may be determined. These lines, JJ and UU, are shown as calculated by the formulæ for both jacketed and unjacketed cylinders, in the experiments made with the jacket drain-cock shut, Plate 128.

The author has analyzed, so far as the published data permit, the series of experiments made by Mr. Willans on a non-condensing engine and described in his paper read before the Institution of Civil Engineers in March 1888.* Table 12 and Plates 129 to 131 have been prepared to show the comparative weights of water per stroke observed by Mr. Willans, and those calculated from the same data by the author's formula for jacketed cylinders. The calculations have been made on the basis that the portion of clearance surface which is practically jacketed in Mr. Willans's engine is the entire cylinder cover. The author is not sufficiently familiar with the construction of the engine to be sure whether this exactly represents the case, and unfortunately for the comparison, the number of thermal units abstracted per stroke is given by Mr. Willans for the point of cut-off only. The calculated amounts for this point are given in Table 12, but it is not practicable to make a full comparison of the observed condensation at different points of the stroke, with the calculated amounts.

Conclusions.—A consideration of the author's formulæ will show that according to them the loss caused by excess of condensation over re-evaporation, at the end of the stroke, may be reduced in three separate and independent ways: the first is to proportion the cylinder in such a manner that the re-evaporation during the stroke may as far as possible balance the condensation at the commencement; the second is to increase the rate of revolution; and the third is to reduce the area of unjacketed clearance surface to a minimum.

The first of these was alluded to by the author in his previous paper, with an example designed to show that, for working a single unjacketed cylinder at all economically, it is absolutely necessary that the stroke should be increased, in relation to the diameter, to far beyond the usual proportions. If the latter are adhered to, and a small weight of steam, designed to expand several times, is introduced per stroke, it must be contained in such a shape at cut-off

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* Proceedings of the Institution of Civil Engineers 1888, vol. xciii, page 128.

as to render it unavoidable that a large proportion should be initially condensed ; and further there will not be sufficient re-evaporative surface exposed during the stroke to recover the heat thus communicated to the metal. If on the other hand a larger weight of steam is introduced, by using a late cut-off, the loss due to not being able to work expansively will more than counterbalance the saving of condensation. The proved economy of compound and triple cylinders is in great measure due, in the author's opinion, to the weight of steam enclosed at cut-off in each cylinder being generally large in proportion to the amount condensed on the clearance surface ; whilst expansive working, though not carried out as economically in itself as it can be in a single cylinder, is yet conducted without any very serious loss.

The second method of avoiding initial condensation, by a higher speed of revolution, appears to be productive of unmixed gain, as far as the actual working of the steam is concerned; but it is of course generally limited by practical considerations.

The third method, by reducing the area of unjacketed clearance surface as far as possible, appears to the author to be unattended with any counterbalancing disadvantages ; and he is of opinion that it is of greater importance effectually to jacket the cylinder covers and piston than the sides of the cylinder themselves; and that the economical results obtained by Corliss and other similar valve-gear are more directly attributable to short steam-passages and consequent reduction of clearance surface, than to any other cause.

In conclusion, the author is fully aware that no general formulæ for such complicated conditions as prevail in a steam cylinder can be expected to give more than approximate results. He ventures to express a hope that those which he has put forward may be regarded, not as representing any particular theory, but as the outcome of an attempt to supply the want, which he has often experienced in practice, of some basis of calculation, even though an imperfect one, for the steam likely to be used in any given engine.

TABLES 9 to 12.

TABLE 9. (*continued to page 665*)

Results of Trials made to ascertain
Water used per stroke
and Steam Pressures.

Series of trials		I		II		a
Register number of trial	No.	43	44	46	47	b
Duration of trial	mins.	360	300	191	180	c
Revolutions, total during trial	revs.	42234	35579	21920	20919	d
Thermometer	Fahr.	65°	76°	70°	70°	e
Barometer, inches of mercury	ins.	30·2	30·0	30·0	29·9	f
Vacuum, inches of mercury	ins.	21·0	22·0	24·0	24·0	g
Boiler pressure per sq. inch above atm.	lbs.	42	44	60	60	h
Feed Water, total	lbs.	3195	2539	3192	3140	i
Collected Water. Total	lbs.	3122	2491	3114	3079	j
Collected Water. From Cylinders during trial	lbs.	3075	2438	3035	2971	k
Collected Water. ,, Jacket ,, ,,	lbs.	0	0	0	0	l
Collected Water. ,, Jacket drain-cock after trial	lbs.	17	17	27	27	m
Steam Pressures, lbs. per square inch. Admission, absolute		48·2	49·6	67·9		n
Forward, absolute at point A on diagram*		25·8	27·7	45·7		o
,, ,, ,, ,, B ,, ,,		10·8	11·7	19·7		p
Terminal, absolute		7·8	8·6	14·5		q
Back pressure, absolute, beginning of compression		5·1	5·7	5·0		r
Cushion pressure, absolute, end of stroke		9·3	10·5	10·1		s
Mean Forward Pressure up to point A on diagram*		37·6	41·4	61·3		
Mean Forward Pressure ,, ,, ,, B ,, ,,		22·2	23·3	38·0		u
Mean Forward Pressure throughout stroke		16·0	17·0	29·6		v
Mean Back pressure throughout stroke		3·0	3·7	3·2		w
,, Cushion ,, ,, ,,		1·9	2·0	2·5		x
,, Effective ,, ,, ,,		11·1	11·3	23·9		y
Number of Indicator Diagrams taken in trial		95		48		z
* See diagrams in Plate		119		119		

(continued on next page) TABLE 9.

Results of Trials made to ascertain Water used per stroke and Steam Pressures.

a	III		IV	V				
b	16	17	39	14	15	26	28	42
c	60	60	60	60	60	360	60	360
d	7259	7161	7252	7107	7203	43891	7359	44257
e	68°	68°	62°	66°	65°	66°	69°	76°
f	29·6	29·6	29·9	29·7	29·6	30·0	29·7	30·0
g	26·0	26·0	15·0	26·5	26·0	26·0	25·5	24·0
h	55	55	50	70	70	70	70	70
i	1295	1195	600	1550	1220	6162	1494	6256
j	1351	1261	520	1434	1185	?	1394	6157
k	989	1027	428	963	1014	?	978	5877
l	0	0	0	0	0	0	0	0
m	22	21	21	23	19	20	3	27
n	60·5	60·2	58·1	73·9	75·0	72·7	72·0	74·8
o	45·8	44·1	33·3	54·9	54·0	52·9	54·8	54·2
p	19·2	19·2	13·9	20·9	20·7	20·0	20·5	19·8
q	14·3	14·2	9·2	13·7	14·0	13·8	14·1	13·6
r	4·3	4·0	7·9	4·5	4·4	5·8	5·1	5·2
s	7·7	7·6	17·2	7·3	7·6	16·5	16·1	9·8
t	57·6	58·5	42·4	69·4	68·8	68·6	69·9	66·3
u	36·8	38·5	23·8	40·4	40·0	40·1	40·5	38·7
v	28·9	30·1	18·0	29·5	29·3	30·0	29·9	28·8
w	3·1	2·9	4·9	3·2	2·9	2·8	3·4	3·5
x	1·5	1·5	3·7	1·4	1·5	2·0	1·8	1·9
y	24·3	25·7	9·4	24·9	24·9	25·2	24·7	23·4
z	40 120		16 120	152 121				

TABLE 9 (*continued from preceding page*)

Results of Trials made to ascertain
Water used per stroke
and Steam Pressures.

Series of trials		VI	VII			*a*
Register number of trial	No.	38	52	54	53	*b*
Duration of trial	mins.	60	60	60	360	*c*
Revolutions, total during trial	revs.	7212	7172	7256	42918	*d*
Thermometer	Fahr.	62°	66°	67°	67°	*e*
Barometer, inches of mercury	ins.	30·0	29·8	29·9	29·9	*f*
Vacuum, inches of mercury	ins.	18·5	21·5	21·0	21·0	*g*
Boiler pressure per sq. inch above atm.	lbs.	55	55	55	55	*h*
Feed Water, total	lbs.	1199	784	794	4490	*i*
Collected Water. Total	lbs.	1164	745	757	4349	*j*
Collected Water. From Cylinders during trial	lbs.	958	654	705	4258	*k*
Collected Water. ,, Jacket ,, ,,	lbs.	72	0	0	0	*l*
Collected Water. ,, Jacket drain-cock after trial	lbs.	0	24	12	25	*m*
Steam Pressure, lbs. per square inch. Admission, absolute		63·1	59·5		59·8	*n*
Forward, absolute at point A on diagram*		54·0	39·0		40·4	*o*
,, ,, ,, ,, B ,, ,,		22·8	15·7		16·3	*p*
Terminal, absolute		16·0	11·0		11·3	*q*
Back pressure, absolute, beginning of compression		7·0	5·5		5·7	*r*
Cushion pressure, absolute, end of stroke		16·7	11·5		15·6	*s*
Mean Forward Pressure up to point A on diagram*		61·5	51·0		52·0	*t*
Mean Forward Pressure ,, ,, ,, B ,, ,,		42·5	29·5		30·6	*u*
Mean Forward Pressure throughout stroke		33·2	22·5		23·3	*v*
Mean Back pressure throughout stroke		4·0	3·3		3·3	*w*
,, Cushion ,, ,, ,,		3·4	2·2		2·1	*x*
,, Effective ,, ,, ,,		25·8	17·0		17·9	*y*
Number of Indicator Diagrams taken in trial		16	76			*z*
* See diagrams in Plate		121	122			

(*continued on next page*) TABLE 9.

Results of Trials made to ascertain Water used per stroke and Steam Pressures.

a	VIII		IX	X	XI		
b	45	55	35	37	23	24	25
c	360	60	60	60	60	360	60
d	42642	7395	7134	7159	7219	43676	7240
e	76°	67°	62°	62°	62°	62°	70°
f	30·0	29·9	30·2	30·2	30·1	29·8	30·0
g	22·0	21·0	18·5	18·5	0	0	0
	44	44	70	55	80	80	80
i	2619	447	1250	1218	1611	6814	1655
j	2483	450	1076	1119	1573	6734	1568
k	2185	357	974	956	1093	6461	1068
l	230	40	0	0	0	0	0
m	0	0	21	20	19	3	13
n	49·8	51·3	77·0	61·7	85·7	85·2	85·3
o	27·4	26·3	63·0	51·8	70·0	67·5	65·3
p	11·3	11·3	22·6	21·2	29·4	28·3	28·0
q	8·1	7·8	15·1	15·2	20·0	20·1	19·6
r	5·8	4·9	7·0	6·8	14·8	14·8	14·8
s	10·6	9·0	16·0	14·8	32·2	32·2	31·0
t	39·6	39·2	74·0	60·0	83·0	83·4	82·7
u	21·6	18·7	44·2	41·1	55·2	53·6	54·0
v	16·1	15·7	32·7	31·6	43·3	42·4	39·5
w	3·4	3·1	4·0	4·1	9·2	8·4	9·2
x	2·1	1·8	2·9	2·9	7·3	7·1	6·4
y	10·6	10·8	25·8	24·6	26·8	26·9	23·9
z	64		20	16	74		
	122		123	123	124		

TABLE 9. (*continued from preceding page*)

Results of Trials made to ascertain
Water used per stroke
and Steam Pressures.

Series of trials			XII			a
	Register number of trial	No.	49	50	51	b
	Duration of trial	mins.	360	60	60	c
	Revolutions, total during trial	revs.	42569	7197	7130	d
	Thermometer	Fahr.	63°	65°	66°	e
	Barometer, inches of mercury	ins.	29·8	29·8	29·8	f
	Vacuum, inches of mercury	ins.	21·5	21·5	21·5	g
	Boiler pressure per sq. inch above atm.	lbs.	55	55	55	h
	Feed Water, total	lbs.	4374	707	756	i
Collected Water.	Total	lbs.	4202	686	679	j
Collected Water.	From Cylinders during trial	lbs.	3938	634	550	k
Collected Water.	,, Jacket ,, ,,	lbs.	230	38	55	l
Collected Water.	,, Jacket drain-cock after trial	lbs.	0	0	0	m
Steam Pressure, lbs. per square inch.	Admission, absolute		59·5	60·3		n
Steam Pressure, lbs. per square inch.	Forward, absolute at point A on diagram *		35·5	40·3		o
Steam Pressure, lbs. per square inch.	,, ,, ,, ,, B ,, ,,		15·7	15·9		p
Steam Pressure, lbs. per square inch.	Terminal, absolute		11·4	10·7		q
Steam Pressure, lbs. per square inch.	Back pressure, absolute, beginning of compression		5·4	5·4		r
Steam Pressure, lbs. per square inch.	Cushion pressure, absolute, end of stroke		8·2	10·8		s
Steam Pressure, lbs. per square inch.	Mean Forward Pressure up to point A on diagram *		49·0	52·7		t
Steam Pressure, lbs. per square inch.	Mean Forward Pressure ,, ,, ,, B ,, ,,		31·0	31·0		u
Steam Pressure, lbs. per square inch.	Mean Forward Pressure throughout stroke		23·8	23·1		v
Steam Pressure, lbs. per square inch.	Mean Back pressure throughout stroke		3·3	3·3		w
Steam Pressure, lbs. per square inch.	,, Cushion ,, ,, ,,		1·6	2·1		x
Steam Pressure, lbs. per square inch.	,, Effective ,, ,, ,,		18·9	17·7		y
	Number of Indicator Diagrams taken in trial		80			z
	* See diagrams in Plate		124			

(*continued on next page*) TABLE 9.

Results of Trials made to ascertain Water used per stroke and Steam Pressures.

a	XIII	XIV			XV		
b	48	18	21	22	9	10	11
c	360	60	60	360	60	60	60
d	41500	7146	7205	43559	7251	7217	7228
e	65°	74°	68°	65°	65°	64°	66°
f	29·8	29·8	30·3	30·2	30·3	30·3	30·3
g	22·0	0	0	0	27·5	27·5	27·0
h	56	80	80	80	55	55	55
i	4980	1422	1334	6367	1169	1096	1191
j	4828	1401	1240	6198	1189	1054	1149
k	4422	936	958	5788	822	826	789
l	340	61	42	249	62	39	48
m	0	0	0	0	0	0	0
n	63·5	86·0	86·5	86·4	62·0	61·4	60·7
o	45·2	68·3	68·8	68·0	47·0	46·8	42·8
p	19·5	29·6	28·4	27·8	20·2	19·9	18·8
q	13·9	20·6	19·3	18·8	13·8	13·9	12·2
r	5·3	14·8	14·8	14·8	3·8	4·1	3·8
s	10·0	30·9	32·2	31·0	6·8	7·3	7·3
t	57·5	81·6	80·6	81·6	58·2	59·4	55·5
u	36·6	54·6	53·6	53·8	37·2	39·5	35·1
v	28·8	42·8	41·8	41·6	28·7	30·9	27·7
w	3·5	8·9	8·7	8·7	2·5	3·5	2·9
x	1·9	6·0	6·3	7·6	1·3	1·4	1·4
y	23·4	27·9	26·8	25·3	24·9	26·0	23·4
z	48 125	56 125			54 126		

TABLE 9. (*continued from preceding page*)

Results of Trials made to ascertain Water used per stroke and Steam Pressures.

Series of trials			XVI			a
	Register number of trial	No.	12	13	41	b
	Duration of trial	mins.	60	60	360	c
	Revolutions, total during trial	revs.	7234	7353	43682	d
	Thermometer	Fahr.	65°	65°	66°	e
	Barometer, inches of mercury	ins.	30·4	30·4	30·1	f
	Vacuum, inches of mercury	ins.	27·0	27·0	24·0	g
	Boiler pressure per sq. inch above atm.	lbs.	70	70	70	h
	Feed Water, total	lbs.	1031	1145	5194	i
Collected Water.	Total	lbs.	1021	1136	5172	j
Collected Water.	From Cylinders during trial	lbs.	790	768	4698	k
Collected Water.	„ Jacket „ „	lbs.	76	62	328	l
Collected Water.	„ Jacket drain-cock after trial	lbs.	0	0	0	m
Steam Pressure, lbs. per square inch.	Admission, absolute		75·5	75·5	76·1	n
Steam Pressure, lbs. per square inch.	Forward, absolute at point A on diagram*		51·7	51·1	52·9	o
Steam Pressure, lbs. per square inch.	„ „ „ „ B „ „		20·2	20·0	21·5	p
Steam Pressure, lbs. per square inch.	Terminal, absolute		12·5	12·5	13·3	q
Steam Pressure, lbs. per square inch.	Back pressure, absolute, beginning of compression		3·9	3·7	5·2	r
Steam Pressure, lbs. per square inch.	Cushion pressure, absolute, end of stroke		6·3	6·1	9·8	s
Steam Pressure, lbs. per square inch.	Mean Forward Pressure: up to point A on diagram*		67·7	70·4	69·0	t
Steam Pressure, lbs. per square inch.	Mean Forward Pressure: „ „ „ B „ „		39·1	41·4	39·3	u
Steam Pressure, lbs. per square inch.	Mean Forward Pressure: throughout stroke		29·5	31·3	30·9	v
Steam Pressure, lbs. per square inch.	Mean Back pressure throughout stroke		2·4	4·1	3·0	w
Steam Pressure, lbs. per square inch.	„ Cushion „ „ „		1·7	1·9	2·7	x
Steam Pressure, lbs. per square inch.	„ Effective „ „ „		25·4	25·3	25·2	y
	Number of Indicator Diagrams taken in trial		88			
	* See diagrams in Plate		126			

(concluded from page 658) TABLE 9.

Results of Trials made to ascertain Water used per stroke and Steam Pressures.

a	XVII	XVIII				
b	40	30	31	32	33	34
c	60	60	60	60	300	60
d	7180	7135	6957	7259	36261	7273
e	63°	66°	70°	66°	62°	63°
f	29·9	29·9	29·9	30·0	30·0	29·9
g	23·0	11·0	18·0	19·5	18·0	18·5
h	40	70	70	70	72	70
i	513	1263	1157	1313	4869	1232
j	434	1191	1035	1159	4905	1146
k	354	878	832	857	4321	873
l	0	74	79	59	333	56
m	19	0	0	0	0	0
n	44·8	78·4	78·0	76·9	78·8	77·8
o	24·8	56·4	51·8	48·3	53·1	60·8
p	11·1	24·0	22·4	21·1	21·8	22·9
q	7·5	16·6	15·5	14·8	14·9	14·9
r	5·2	11·1	7·6	6·6	7·0	6·0
s	7·5	22·4	15·5	13·2	17·0	13·0
t	34·6	72·0	69·8	67·4	74·3	74·7
u	20·5	46·6	44·0	41·6	45·0	45·5
v	14·9	36·2	35·1	31·5	34·9	33·9
w	3·1	6·6	4·3	3·5	4·1	4·3
x	1·5	4·4	3·0	2·6	3·3	2·5
y	10·3	25·2	27·8	25·4	27·5	27·1
z	16 127	110 127				

TABLE 10. (*continued to page 669*)

Comparison of Average Results of Table 9 with Calculation.

			I	II
Series of trials			I	II
Register number of trials		Nos.	43, 44	46, 47
Indicated Horse-Power		I.H.P.	14·8	30·7
Number of Expansions		times	8·5	5·5
Steam Pressure, lbs. per square inch.	Admission, absolute		48·9	67·9
	Terminal, absolute		8·2	14·5
	Back pressure, absolute, beginning of compression		5·4	5·0
	Cushion pressure, absolute, end of stroke		9·9	10·1
	Mean Forward pressure throughout stroke		16·5	29·6
	,, Back ,, ,, ,,		3·4	3·2
	,, Cushion ,, ,, ,,		1·9	2·5
	,, Effective ,, ,, ,,		11·2	23·9
Water per stroke.	From Jacket, collected during trial	lb.	0	0
	,, Cylinder, ,, ,, ,,	lb.	0·0176	0·0350
	,, ,, calculated as unjacketed	lb.	0·0241	0·0393
	,, ,, ,, ,, jacketed	lb.	0·0194	0·0332
	Accounted for by indicator at cut-off	lb.	0·0083	0·0190
Jacket Steam during trial, percentage of total		per cent.	0	0
Cylinder ,, ,, ,, ,, ,, ,,		per cent.	100	100
Work, thermal units.	Total, per lb. of cylinder steam		111	101
	Back-pressure, ,, ,,		22	11
	Cushion, ,, ,,		13	9
	Effective, ,, ,,		76	81
	,, per lb. of steam supplied		76	81
	,, ,, stroke		1·34	2·83
Heat, th. units.	Per lb. of steam supplied		1167	1174
	,, ,, ,, water at back-pressure temperature		134	133
	Available per lb. of steam supplied		1033	1041
	,, ,, stroke, including jacket steam		18·1	36·0
Efficiency, or Effective Work in percentage of Available Heat			7·4	7·7
Water per horse-power per hour, including jacket		lbs.	33·8	31·7
Condensation per stroke, thermal units.	Initial, calculated as unjacketed		16·8	23·2
	,, ,, ,, jacketed		10·8	15·1
	Net at point A on diagrams, calculated as unjacketed		14·5	18·3
	,, ,, ,, ,, ,, ,, ,, ,, jacketed		9·1	11·6
	,, ,, ,, ,, ,, ,, observed		9·3	16·0
	,, at point B on diagrams, calculated as unjacketed		11·0	12·7
	,, ,, ,, ,, ,, ,, ,, ,, jacketed		6·3	7·5
	,, ,, ,, ,, ,, ,, observed		6·3	12·7
	,, at end of stroke, calculated as unjacketed		9·1	9·5
	,, ,, ,, ,, ,, ,, ,, jacketed		4·9	5·0
	,, ,, ,, ,, ,, observed		3·4	9·2

(continued on next page) TABLE 10.

Comparison of Average Results of Table 9 with Calculation.

III	IV	V	VI	VII	VIII	IX
16, 17	39	{14, 15, 26, 28, 42}	38	52, 53, 54	45, 55	35
33·0	13·8	32·8	34·3	23·9	13·7	33·8
5·7	10·0	6·6	4·8	8·0	9·6	6·2
60·3	58·1	73·7	63·1	59·7	50·5	77·0
14·2	9·2	13·7	16·0	11·3	8·1	15·1
4·1	7·9	5·3	7·0	5·7	5·6	7·0
7·6	17·2	12·6	16·7	14·6	10·3	16·0
29·5	18·0	29·4	33·2	23·1	16·0	32·7
3·0	4·9	3·2	4·0	3·3	3·3	4·0
1·5	3·7	1·8	3·4	2·1	2·1	2·9
25·0	9·4	24·4	25·8	17·7	10·6	25·8
0	0	0	0·0025	0	0·0013	0
0·0350	0·0147	0·0339	0·0332	0·0245	0·0127	0·0341
0·0337	—	0·0392	—	0·0289	—	0·0408
0·0284	0·0206	0·0326	0·0312	0·0233	0·0186	0·0339
0·0162	0·0073	0·0172	0·0191	0·0102	0·0072	0·0178
0	0	0	7·0	0	9·2	0
100	100	100	93·0	100	90·8	100
99	151	102	118	114	146	113
10	38	11	14	16	30	14
5	30	6	12	11	19	10
84	83	85	92	87	97	89
84	83	85	86	87	88	89
2·92	1·22	2·88	2·85	2·13	1·12	3·03
1171	1170	1175	1172	1171	1167	1176
122	150	133	145	136	136	143
1049	1020	1042	1027	1035	1031	1033
36·7	15·0	35·3	36·7	25·4	14·4	35·2
8·0	8·1	8·2	8·3	8·4	8·5	8·6
30·5	30·9	30·3	30·0	29·4	29·4	28·8
19·7	—	24·1	—	19·9	—	25·1
13·1	12·6	15·6	13·7	12·8	10·9	16·4
15·0	—	20·3	—	17·0	—	21·0
9·8	10·9	12·8	10·4	10·7	9·4	13·5
16·5	5·0	16·5	12·2	11·9	4·9	14·8
9·2	—	14·3	—	12·3	—	14·1
5·5	8·0	8·4	5·3	7·2	6·9	8·3
13·3	1·1	13·4	8·6	8·3	1·7	11·8
6·2	—	10·6	—	9·3	—	10·5
3·0	6·2	5·6	2·7	4·8	5·3	5·4
9·7	−0·9	10·0	5·8	4·8	−0·9	7·9

TABLE 10. *(continued from preceding page)*

Comparison of Average Results of Table 9 with Calculation.

			X	XI
	Series of trials		X	XI
	Register number of trials	Nos.	37	{23,24, 25}
	Indicated Horse-Power	I.H.P.	32·8	36·2
	Number of Expansions	times	5·0	4·9
Steam Pressure, lbs. per square inch.	Admission, absolute		61·7	85·3
	Terminal ,,		15·2	20·0
	Back pressure, absolute, beginning of compression		6·8	14·8
	Cushion pressure, absolute, end of stroke		14·8	32·1
	Mean Forward pressure throughout stroke		31·6	42·2
	,, Back ,, ,, ,,		4·1	8·6
	,, Cushion ,, ,, ,,		2·9	7·0
	,, Effective ,, ,, ,,		24·6	26·6
Water per stroke.	From Jacket, collected during trial	lb.	0	0
	,, Cylinder, ,, ,, ,,	lb.	0·0334	0·0371
	,, ,, calculated as unjacketed	lb.	0·0354	0·0473
	,, ,, ,, ,, jacketed	lb.	0·0302	0·0402
	Accounted for by indicator at cut-off	lb.	0·0181	0·0238
	Jacket Steam during trial, percentage of total	per cent.	0	0
	Cylinder ,, ,, ,, ,, ,, ,,	per cent.	100	100
Work, thermal units.	Total, per lb. of cylinder steam		113	133
	Back-pressure, ,, ,,		15	25
	Cushion, ,, ,,		10	21
	Effective, ,, ,,		88	87
	,, per lb. of steam supplied		88	87
	,, ,, stroke		2·94	3·23
Heat, th. units.	Per lb. of steam supplied		1172	1178
	,, ,, ,, water at back-pressure temperature		144	181
	Available per lb. of steam supplied		1028	997
	,, ,, stroke, including jacket steam		34·3	37·0
	Efficiency, or Effective Work in percentage of Available Heat		8·6	8·7
	Water per horse-power per hour, including jacket	lbs.	29·1	29·8
Condensation per stroke, thermal units.	Initial, calculated as unjacketed		20·2	27·2
	,, ,, ,, jacketed		13·3	17·9
	Net at point A on diagrams, calculated as unjacketed		15·5	20·8
	,, ,, ,, ,, ,, ,, ,, ,, jacketed		10·0	13·4
	,, ,, ,, ,, ,, ,, observed		13·0	12·4
	,, at point B on diagrams, calculated as unjacketed		8·8	12·3
	,, ,, ,, ,, ,, ,, ,, ,, jacketed		5·1	7·1
	,, ,, ,, ,, ,, ,, observed ,, ,,		9·9	8·1
	,, at end of stroke, calculated as unjacketed		6·1	8·6
	,, ,, ,, ,, ,, ,, ,, jacketed		2·7	4·1
	,, ,, ,, ,, ,, observed		7·0	4·6

(*concluded from page* 666) TABLE 10.

Comparison of Average Results of Table 9 with Calculation.

XII	XIII	XIV	XV	XVI	XVII	XVIII
49, 50, 51	48	18, 21, 22	9, 10, 11	12, 13, 41	40	{30, 31, 32, 33, 34}
24·1	29·1	35·3	32·9	33·1	13·9	36·3
7·3	6·5	5·2	5·6	6·8	9·5	6·1
59·9	63·5	86·4	61·4	75·9	44·8	78·3
11·0	13·9	19·1	13·3	13·1	7·5	15·1
5·4	5·3	14·8	3·9	4·8	5·2	7·4
8·9	10·0	31·1	7·1	8·9	7·5	16·6
23·6	28·8	41·8	29·1	30·8	14·9	34·5
3·3	3·5	8·7	3·0	3·1	3·1	4·4
1·7	1·9	7·2	1·4	2·5	1·5	3·0
18·6	23·4	25·9	24·7	25·2	10·3	27·1
0·0014	0·0020	0·0015	0·0017	0·0020	0	0·0024
0·0225	0·0266	0·0332	0·0281	0·0268	0·0123	0·0299
—	—	—	—	—	—	—
0·0251	0·0283	0·0394	0·0290	0·0325	0·0169	0·0342
0·0121	0·0144	0·0224	0·0167	0·0166	0·0068	0·0182
5·8	7·0	4·4	6·2	7·0	0	7·6
94·2	93·0	95·6	93·8	93·0	100	92·4
122	125	149	123	135	146	139
17	15	30	13	14	30	17
9	9	25	6	11	15	12
96	101	94	104	110	101	109
90	94	90	98	102	101	101
2·02	2·50	2·99	2·75	2·73	1·24	3·02
1171	1172	1179	1172	1176	1165	1177
134	133	181	120	129	132	147
1037	1039	998	1052	1047	1033	1030
24·8	29·7	34·5	31·3	30·2	12·7	33·3
8·7	9·0	9·0	9·3	9·7	9·8	9·8
28·2	27·3	28·4	26·2	25·4	25·5	25·6
—	—	—	—	—	—	—
13·0	14·0	18·1	13·2	16·0	9·9	16·7
—	—	—	—	—	—	—
10·4	10·7	13·7	10·1	13·3	8·4	12·5
8·6	9·2	8·6	9·3	10·2	4·5	9·9
—	—	—	—	—	—	—
6·8	6·5	7·6	5·5	8·8	5·9	7·3
5·5	5·4	4·1	5·7	5·2	0·9	6·5
—	—	—	—	—	—	—
4·9	4·1	4·4	3·3	5·4	4·6	5·0
3·1	2·6	1·8	3·9	3·6	1·1	4·1

TABLE 11. (*continued on opposite page*)

Summary of observed results from Table 10, arranged in each group in order of comparative efficiency.

Condensing or Non-Condensing.		Condensing.						
Series of Trials in Table 10		I	II	III	V	VII	IX	X
Cylinders:— U = Unjacketed J = Jacketed		U	U	U	U	U	U	U
Initial Pressure, absolute, lbs. per square inch		48·9	67·9	60·3	73·7	59·7	77·0	61·7
Number of Expansions		8·5	5·5	5·7	6·6	8·0	6·2	5·0
Back Pressure, absolute, lbs. per square inch		5·4	5·0	4·1	5·3	5·7	7·0	6·8
Thermal Units per stroke.	Effective Work	1·34	2·83	2·92	2·88	2·13	3·03	2·94
	Useless Work	0·62	0·70	0·52	0·58	0·66	0·81	0·83
	Steam and Water at end of stroke	12·7	23·3	23·6	21·8	17·8	23·5	23·5
	Condensation at end of stroke	3·4	9·2	9·7	10·0	4·8	7·9	7·0
	Total Heat excluding Jacket	18·1	36·0	36·7	35·3	25·4	35·2	34·3
	Heat supplied by Jacket	?	?	?	?	?	?	?

The initial pressure, number of expansions, back pressure, effective work, and condensation at end of stroke, are all copied from Table 10.

The useless work is the sum of the back-pressure work (line 21 in Table 10) and of the cushion work (line 22), each per lb. of cylinder steam, multiplied by the weight of water per stroke from the cylinder (line 14).

The thermal units in the condensation at end of stroke are the remainders left after deducting from the total heat (excluding jacket) the effective and useless work and the heat left in the steam and water at end of stroke.

(*continued from opposite page*) TABLE 11.

Summary of observed results from Table 10,
arranged in each group in order of comparative efficiency.

Non-condensing.		Condensing.						Condensing and superheated.		
XI	XIV	VI	XII	XIII	XV	XVI	XVIII	IV	VIII	XVII
U	J	J	J	J	J	J	J	U	J	U
85·3	86·4	63·1	59·9	63·5	61·4	75·9	78·3	58·1	50·5	44·8
4·9	5·2	4·8	7·3	6·5	5·6	6·8	6·1	10·0	9·6	9·5
14·8	14·8	7·0	5·4	5·3	3·9	4·8	7·4	7·9	5·6	5·2
3·23	2·99	2·85	2·02	2·50	2·75	2·73	3·02	1·22	1·12	1·24
1·70	1·83	0·84	0·58	0·64	0·53	0·67	0·87	1·00	0·62	0·55
27·5	26·4	24·6	17·7	21·9	22·2	21·1	22·8	13·7	12·3	12·0
4·6	1·8	5·8	3·1	2·6	3·9	3·6	4·1	−0·9	−0·9	−1·1
37·0	33·0	34·1	23·4	27·6	29·4	28·1	30·8	15·0	13·1	12·7
?	1·5	2·6	1·4	2·1	1·9	2·1	2·5	?	1·3	?

The thermal units left in the steam and water at end of stroke are calculated in the manner detailed in Proceedings 1887, page 492.

The total heat excluding jacket is the sum of the four lines immediately above it, and is the number of thermal units available per stroke (excluding jacket), copied from the diagrams, Plates 119 to 127.

The heat supplied by jacket is the difference between the heat available per stroke including jacket steam, and the heat excluding jacket, taken from the diagrams, Plates 119 to 127.

TABLE 12. (*continued to page* 675)

Comparison of Mr. Willans' Observed results with Calculation.

See Proceedings Inst. C. E. 1888, *vol.* xciii, *pages* 164–169.

P	Admission pressure, absolute, lbs. per square inch.
A	Trial letter, S simple, C compound, T triple; intended absolute mean admission pressure, lbs. per square inch; and intended ratio of expansion.
R	Revolutions per minute.
W	Lb. weight of Steam per stroke, accounted for by indicator at cut-off.
FO	Lb. weight of Feed-Water per stroke, Observed.
FC	Lb. do. do. Calculated $= \rho_1 \left\{ \frac{56}{\sqrt{N}} \frac{S_c - S_1}{L} + (1+c)(1-n)X \right\}$
HO	Heat units per stroke, missing at cut-off, Observed.
HC	Do. do. do. Calculated $= \frac{56}{\sqrt{N}} (S_c - S_1)\rho_1$

Mr. Willans' Table I. See Fig. 41, Plate 129.

A	S $\frac{40}{1\cdot57}$	S $\frac{50}{2\cdot17}$	S $\frac{70}{2\cdot8}$	S $\frac{80}{3\cdot2}$	S $\frac{90}{3\cdot6}$	S $\frac{100}{4}$	S $\frac{110}{4\cdot4}$
R	393·5	408·4	409·1	403·2	400·9	397·7	406·2
W	0·02639	0·02342	0·02486	0·02507	0·02656	0·02531	0·02527
FO	0·0299	0·0290	0·0338	0·0329	0·0353	0·0368	0·0359
FC	0·0273	0·0247	0·0297	0·0299	0·0327	0·0321	0·0329
HO	3·269	5·166	8·168	7·048	7·863	10·261	9·436
HC	0·8	1·2	3·4	4·2	5·4	6·0	6·7

Mr. Willans' Table II. Ratio of Expansion $= \frac{P}{25}$. See Fig. 43, Plate 130.

A	C $\frac{80}{3\cdot2}$	C $\frac{90}{3\cdot6}$	C $\frac{100}{4}$	C $\frac{110}{4\cdot4}$	C $\frac{120}{4\cdot8}$	C $\frac{130}{5\cdot2}$	C $\frac{140}{5\cdot6}$
R	400·0	397·6	405·3	402·7	404·1	401·9	405·1
W	0·02576	0·02478	0·02410	0·02435	0·02485	0·02397	0·02506
FO	0·0272	0·0268	0·0269	0·0275	0·0284	0·0279	0·0294
FC	0·0268	0·0267	0·0267	0·0279	0·0289	0·0288	0·0306
HO	1·271	1·819	2·459	2·748	3·122	3·468	3·781
HC	1·0	1·7	2·3	2·9	3·5	4·2	4·8

(*continued on next page*) TABLE 12.

Comparison of Mr. Willans' Observed results with Calculation.

See Proceedings Inst. C. E. 1888, *vol.* xciii, *pages* 166–173.

	Mr. Willans' Table II. Ratio of Expansion $= \frac{P-10}{25}$. See Fig. 44, Plate 130.							
A	C $\frac{90}{3\cdot2}$	C $\frac{100}{3\cdot6}$	C $\frac{110}{4}$	C $\frac{120}{4\cdot4}$	C $\frac{130}{4\cdot8}$	C $\frac{140}{5\cdot2}$	C $\frac{150}{5\cdot6}$	C $\frac{160}{6}$
R	401·1	401·5	402·9	402·7	405·5	398·7	404·0	401·2
W	0·02768	0·02686	0·02641	0·02673	0·02672	0·02642	0·02627	0·02616
FO	0·0292	0·0286	0·0292	0·0299	0·0303	0·0307	0·0310	0·0315
FC	0·0289	0·0290	0·0293	0·0304	0·0311	0·0316	0·0321	0·0327
HO	1·404	1·586	2·464	2·742	3·110	3·742	4·091	4·657
HC	1·1	1·9	2·5	3·2	3·8	4·5	5·1	5·6

	Mr. Willans' Table III. See Fig. 51, Plate 131.				
	Ratio of Expansion $= \frac{P}{25}$		Ratio of Expansion $= \frac{P-10}{25}$		
A	T $\frac{150}{6}$	T $\frac{160}{6\cdot4}$	T $\frac{150}{5\cdot6}$	T $\frac{160}{6}$	T $\frac{170}{6\cdot4}$
R	409·0	408·4	405·6	401·2	400·4
W	0·02578	0·02596	0·02734	0·02764	0·02805
FO	0·0268	0·0279	0·0289	0·0289	0·0295
FC	0·0261	0·0273	0·0273	0·0280	0·0290
HO	1·285	1·632	1·316	1·101	1·263
HC	0·3	0·7	0·0	0·3	0·8

	Mr. Willans' Table IV. See Fig. 48, Plate 131.						
A	C $\frac{130}{4}$	C $\frac{130}{4\cdot4}$	C $\frac{130}{4\cdot8}$	C $\frac{130}{5\cdot2}$	C $\frac{130}{5\cdot6}$	C $\frac{130}{6}$	C $\frac{130}{8}$
R	406·8	405·0	405·5	401·9	402·6	400·0	404·4
W	0·03098	0·02876	0·02672	0·02397	0·02323	0·02155	0·01649
FO	0·0340	0·0320	0·0303	0·0279	0·0271	0·0264	0·0220
FC	0·0344	0·0327	0·0311	0·0288	0·0284	0·0270	0·0227
HO	2·679	2·86	3·110	3·468	3·395	4·291	4·848
HC	3·0	3·4	3·8	4·2	4·5	4·7	5·4

TABLE 12. (*continued from preceding page*)

Comparison of Mr. Willans' Observed results with Calculation.

See Proceedings Inst. C. E. 1888, *vol.* xciii, *pages* 174–177.

A { Trial letter, S simple, C compound, T triple; intended absolute mean admission pressure, lbs. per square inch; and intended ratio of expansion.
R Revolutions per minute.
W Lb. weight of Steam per stroke, accounted for by indicator at cut-off.
FO Lb. weight of Feed-Water per stroke, Observed.
FC Lb. do. do. Calculated $= \rho_1\left\{\frac{56}{\sqrt{N}}\,\frac{S_c - S_1}{L} + (1+c)(1-n)X\right\}$
HO Heat units per stroke, missing at cut-off, Observed.
HC Do. do. do. Calculated $= \frac{56}{\sqrt{N}}(S_c - S_1)\rho_1$

	Mr. Willans' Table V (*continued below*). See Figs. 39–40, Plate 129.					
A	$S\,\frac{50}{2\cdot174}$			$S\,\frac{70}{2\cdot8}$		
R	408·4	200·6	110·5	409·1	205·2	112·7
W	0·02342	0·02462	0·02488	0·02486	0·02574	0·02590
FO	0·0290	0·0323	0·0380	0·0338	0·0393	0·0478
FC	0·0247	0·0264	0·0273	0·0297	0·0313	0·0332
HO	5·166	7·139	11·97	8·168	12·262	19·864
HC	1·2	1·7	2·2	3·4	5·0	6·6

	Mr. Willans' Table V (*continued from above*). See Figs. 39–40, Plate 129.					
A	$S\,\frac{90}{3\cdot6}$			$S\,\frac{110}{4\cdot4}$		
R	400·9	223·0	122·8	406·2	223·7	138·0
W	0·02656	0·02616	0·02657	0·02527	0·02659	0·0274
FO	0·0353	0·0348	0·0461	0·0359	0·0461	0·0494
FC	0·0327	0·0340	0·0372	0·0329	0·0371	0·0413
HO	7·863	7·564	17·523	9·436	14·338	19·475
HC	5·4	7·0	9·5	6·7	9·3	11·8

(*concluded from page* 672) TABLE 12.

Comparison of Mr. Willans' Observed results with Calculation.

See Proceedings Inst. C. E. 1888, *vol.* xciii, *pages* 178–185.

Mr. Willans' Table VI. See Figs. 45 to 47, Plate 130.

A	C $\frac{90}{3\cdot2}$			C $\frac{110}{4}$			C $\frac{130}{4\cdot8}$		
R	401·1	210·8	122·0	402·9	212·0	123·8	405·5	216·4	130·9
W	0·02768	0·02920	0·02951	0·02641	0·02645	0·02753	0·02672	0·02692	0·02686
FO	0·0292	0·0334	0·0370	0·0292	0·0332	0·0368	0·0303	0·0333	0·0382
FC	0·0289	0·0309	0·0318	0·0293	0·0304	0·0328	0·0311	0·0329	0·0346
HO	1·404	3·786	6·682	2·464	6·000	8·230	3·110	5·611	9·94
HC	1·1	1·5	2·0	2·5	3·5	4·6	3·8	5·0	6·7

Mr. Willans' Table VII. See Fig. 42, Plate 130. * Throttled

A	C $\frac{60}{4}$	C $\frac{70}{4}$	C $\frac{80}{4}$	C $\frac{90}{4}$	C $\frac{100}{4}$	C $\frac{110}{4}$	C $\frac{120}{4}$	C $\frac{130}{4}$	*C $\frac{60}{4}$*
R	399·9	413·1	399·8	405·7	405·3	402·9	409·6	406·8	400·3
W	0·01508	0·01745	0·02103	0·02169	0·02410	0·02641	0·02852	0·03099	0·01447
FO	0·0183	0·0206	0·0224	0·0250	0·0269	0·0292	0·0325	0·0340	0·0171
FC	0·0167	0·0194	0·0232	0·0241	0·0267	0·0293	0·0317	0·0344	0·0161
HO	2·931	2·845	2·055	2·959	2·459	2·464	3·505	2·679	2·405
HC	1·5	1·7	1·9	2·1	2·3	2·5	2·8	3·0	1·5

Mr. Willans' Tables VIII and IX. See Figs. 49 and 50, Plate 131.

	Table VIII. Fig. 49.			Table IX. Fig. 50.			
A	C $\frac{160}{5\cdot2}$	C $\frac{160}{5\cdot6}$	C $\frac{160}{6}$	C $\frac{130}{5\cdot6}$	C $\frac{140}{5\cdot6}$	C $\frac{150}{5\cdot6}$	C $\frac{160}{5\cdot6}$
	421·7	411·3	401·2	402·6	405·1	404·1	411·3
W	0·02985	0·02773	0·02616	0·02323	0·02506	0·02627	0·02773
FO	0·0344	0·0325	0·0315	0·0271	0·0294	0·0310	0·0325
FC	0·0355	0·0339	0·0327	0·0284	0·0306	0·0321	0·0339
HO	3·894	4·095	4·656	3·396	3·781	4·091	4·095
HC	4·8	5·3	5·6	4·5	4·8	5·1	5·3

Discussion.

Mr. P. W. Willans thought any experiments of the sort described in the paper just read must throw great light on matters which all engineers wished to investigate. In making his own trials, which had been alluded to in the paper, he had started with very different opinions from the author's; and after reading the paper he did not feel inclined to alter his opinions.

In page 643 it was stated that, in order to measure as accurately as practicable the quantity of feed-water used, it was determined to weigh both the feed-water into the boiler, and also the condensed water after passing through the engine. After doing this the author came to the conclusion (page 644) that it was best to weigh the water as it came out; and he asked why that was considered the best plan.

Major English replied the only reason was because there were a great many slight discrepancies in the weight of the feed-water.

Mr. Willans said it appeared to him that the figures calculated from the water collected as it came out from the engine showed more economical results than those calculated from the water supplied, because in most trials the water coming out seemed less than the water which went in; but he wished to understand the author's ground for considering that the former were more accurate. In some of his own intended trials he was going to measure the water when it came out. There were many cases in the paper where there was as much as 10 per cent. difference between the water going in and the water coming out; and of course such a difference must much affect the economical result.

The President asked what Mr. Willans thought would be the real difference between the water going in and that coming out.

Mr. Willans was unable to say, and he did not see why there should be any difference; he had made the enquiry only in order to know whether there was any real reason for taking the figures for

the weight of the water as it came out from the engine in preference to as it went into the boiler. In Table 9 the total collected water in line *j* did not agree with the water collected from the cylinders and from the jacket together in lines *k*, *l*, and *m*: which seemed rather puzzling.

Major English explained that the total collected water included all the water passing through the engine from the commencement of firing with weighed coal, and was given separately in line *j* in Table 9. There was therefore no reason why it should agree with the water shown in lines *k*, *l*, and *m*, which was that coming out from the engine during the number of revolutions indicated by the counter.

Mr. Willans considered the feed-water, being really the water going in, was comparable with the water collected from the cylinders and jackets.

Major English said it was comparable only with the total water collected, not with the water collected from the cylinders. The total collected water was the water collected during the whole time that evaporation was going on from the burning of weighed coal; but the water collected from the cylinders and jacket was the water collected only during the connection of the engine with the counter.

Mr. Willans thought it was important that the distinction should be made clear; but there appeared even then to be grave differences between the feed-water and the collected water. For in series IV of Table 9 (page 659) the feed-water was given as 600 lbs., while the total water collected was only 520 lbs., showing a difference of 13 per cent., which had the appearance of being rather a serious difference in trials of this kind.

In the conclusions at the end of the paper (page 655) three ways were mentioned for reducing the loss caused by excess of condensation over re-evaporation at the end of the stroke. But he himself did not admit that there was any loss from the excess of

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condensation over re-evaporation. As he understood the diagrams in Plates 119 to 127, the heat units had been deduced from the water missing at certain points of the stroke: that is, at the point A in Fig. 1, for instance, the steam pressure had been measured and the steam present calculated, and the heat units corresponding with the condensation of the steam not so accounted for had been plotted downwards in Fig. 2 from the zero or datum line, and similarly at the point B; and thence certain conclusions had been deduced. But it appeared to him that the author had omitted to take account of the water which had been formed, due to the work done during the period between the cut-off and the point of measurement; and in some of the diagrams this omission was all the more serious a matter because the figures actually showed an excess of re-evaporation (see Figs. 8, 16, and 34). This excess appeared to be in spite of work done; and therefore the omission appeared to him seriously to affect the results. The paper seemed to proceed on the assumption that it was desirable that re-evaporation should as far as possible balance condensation: not merely, he imagined, that the re-evaporation after the cut-off should balance the condensation before; but that the whole condensation and re-evaporation in the entire stroke should balance each other. The latter was a physical impossibility: they could not do so. The other might happen; or again the re-evaporation after the point of cut-off might balance or more than balance during the forward stroke the condensation after the point of cut-off, but this could only be in an engine working under excessively bad conditions; this at least was his own experience, in cases where a jacket was not in use. In his own trials with simple engines, as a matter of fact the re-evaporation after the point of cut-off exceeded the condensation; and it would do so wherever the initial condensation was very large; but in all those cases the efficiency was extremely low. The balance of condensation before cut-off and of re-evaporation after was therefore not a thing to aim at in any way; and accordingly engineers should not be satisfied with large initial condensation accompanied by large subsequent re-evaporation, but should aim at reducing both to the smallest possible amounts.

In order to arrive at this balance it was then argued by the author (page 655) that it was desirable to have a very long cylinder of a comparatively small diameter. His own trials however had been made on an engine which was proportioned the other way, with a large diameter of cylinder and a short stroke; and even when it was tried at the slowest speed, most unfavourable to that particular kind of engine which presented so large an extent of surface to the steam, the results were broadly speaking more favourable than the author's under similar conditions. In page 646 it was stated that the several series of trials had been grouped in Tables 9 and 10 in the order of their comparative efficiency. For the purpose however of comparing them more readily with his own figures, he had re-arranged the trials in the order of increasing steam-pressure, as shown in Table 13, on page 680. Starting from the left-hand end of the Table, the first three series of trials were made with 45 to 50 lbs. steam, the first two being unjacketed, and the third jacketed; then came four unjacketed series at about 60 lbs., and then four jacketed, also at about 60 lbs.; next followed three unjacketed at 68 to 77 lbs., and then two jacketed at about the same pressure; and last of all came two non-condensing series, one not jacketed and one jacketed, at about 85 and 86 lbs. pressure. It appeared to him that, by grouping these series in the order of efficiency in Tables 9 and 10, the fact was lost sight of that there were serious discrepancies between the groups of trials. For instance, the group which was ranked in Tables 9 and 10 as No. XVII, because it showed so high an efficiency, he himself had put first in Table 13 because it had the lowest steam-pressure, namely 44·8 lbs. only; and when this was compared with the next higher in pressure, which was No. I in Tables 9 and 10 with a steam-pressure of 48·9 lbs., the expansions were not very different, being 9·5 and 8·5 times respectively, but the water per horse-power per hour including the jacket was in the one case 25·5 lbs. and in the other 33·8 lbs. It seemed to him that, when these two groups of trials were thus brought into juxtaposition, this was a large discrepancy to get in the water, bearing in mind that the comparison was not between single indicator diagrams, but between groups of

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TABLE 13.—*Re-arrangement of results from Table* 10.

1 Series of trials in Tables 9 and 10.
2 Cylinders: U = Unjacketed; J = Jacketed.
3 Steam Pressure, absolute on admission, lbs. per square inch, from Table 10.
4 Number of Expansions, from Table 10.
5 Initial Condensation, being excess of water collected from cylinder per stroke above water accounted for by indicator at cut-off, in percentage of water collected from cylinder per stroke; from Table 10.
6 Back Pressure, absolute, lbs. per square inch, from Table 10.
7 Water, lbs. per horse-power per hour, including jacket, from Table 10.
8 Range of Temperature in steam, degrees Fahr., from admission pressure in line 3 to back pressure in line 6.

																	Non-condensing.	
1	XVII	I	VIII	IV	VII	III	X	XV	XII	XIII	VI	II	V	IX	XVII	XVI	XI	XIV
2	U	U	J	U	U	U	U	J	J	J	J-	U	U	U	J	J	U	J
3	44·8	48·9	50·5	58·1	59·7	60·3	61·7	61·4	59·9	63·5	63·1	67·9	73·7	77·0	78·3	75·9	85·3	86·4
4	9·5	8·5	9·6	10·0	8·0	5·7	5·0	5·6	7·3	6·5	4·8	5·5	6·6	6·2	6·1	6·8	4·9	5·2
5	45%	53%	43%	50%	58%	51%	46%	41%	46%	46%	43%	41%	49%	48%	39%	38%	36%	33%
6	5·2	5·4	5·6	7·9	5·7	4·1	6·8	3·9	5·4	5·3	7·0	5·0	5·3	7·0	7·4	4·8	14·8	14·8
7	25·5	33·8	29·4	30·9	29·4	30·5	29·1	26·2	28·2	27·3	30·0	31·7	30·3	28·8	25·6	25·4	29·8	28·4
8	110	114	115	108	125	139	119	142	127	132	119	139	142	132	131	148	101	105

trials and groups of indicator diagrams of not less than sixteen in any one trial. Both series of trials, No. I and No. XVII, were unjacketed; and when alongside them was placed the next in order of increasing steam-pressure, namely the jacketed series No. VIII with 50·5 lbs. pressure, it appeared to him that the figures were so widely discrepant as to allow of arguing from them in almost any direction. One person who did not believe in jackets might support his view by arguing that, while in No. XVII with 44·8 lbs. pressure and no jacket the efficiency was 9·8 in Table 10, it was only 8·5 in No. VIII with 50·5 lbs. pressure and with the jacket in use; but another person who did believe in jackets might say that No. VIII was so much more economical than No. I, because in No. VIII with the jacket in use the efficiency was higher and the water consumption lower than in No. I without the jacket. Before therefore any definite conclusions could really be arrived at, he thought that trials or groups of trials were wanted which should be rather more concordant in the figures they gave.

In pages 647 and 648 the opinion was strongly expressed that the range of temperature in the cylinder had comparatively little to do with the condensation. In the discussion upon the author's former paper (Proceedings 1887, page 529) he had pointed out an example in which the initial condensation in a condensing engine appeared to be less than in a non-condensing engine, in spite of the smaller range of temperature in the cylinder of the latter. In the trials recorded in the present paper there did not appear to be a sufficient difference in range of temperature for enabling any decided opinion to be formed upon the relation between range of temperature and initial condensation. Thus in Table 13, where there was only 5° difference in range of temperature between group XVII and groups I and VIII, the initial condensation varied no less than from 45 per cent. to 53 and then back to 43 per cent. Altogether in Table 13, excluding the last two non-condensing groups, the utmost difference in the range of temperature was seen to be only 40°, namely from 108° to 148°. There were also discrepancies in the water consumption in similar trials, the water per horse-power per hour in group I being about 33 per

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cent. greater than in group XVII. So that it appeared to him to be idle to argue either one way or the other, as to either the existence or the absence of any relation between range of temperature and initial condensation: the recorded figures were hardly close enough to bring out in clear relief such a relation if it did exist. Moreover it seemed to him that these ranges of temperature were all much too high for a single cylinder, and consequently that from such an engine it was idle to hope for economical results in any case; the expansion in the single cylinder was seen in Table 13 to range from 4·8 times to as high as 10·0 times, and it was not surprising therefore that the initial condensation rose as high as 58 per cent. These percentages he had calculated from the figures given in Table 10 of the water collected from the cylinder per stroke and of the water accounted for by the indicator at the point of cut-off; and assuming them to be correct, it was seen that in the highest instance as much as 58 per cent. of the steam which went into the cylinder was condensed before cut-off. In the two groups of non-condensing trials, Nos. XI and XIV, where the range of temperature was least, namely 104° and 105°, it would be seen that the initial condensation had gone down to 36 per cent. and 33 per cent. only: which was in accordance with the effect of reduced range of temperature in other engines. All through the trials with such an engine he should have been inclined to say that jackets ought to do a great deal of good; but in some way or other the jacketing seemed not to have been well arranged. In the non-jacketed trials it appeared from page 646 that the water which was in the jackets had not been debited, and the curious method had been adopted of putting the jackets out of action by shutting the jacket drain-cock; probably that was owing to some peculiarity in the construction of the engine.

Major English said it was impossible to do otherwise.

Mr. Willans inferred that, during the first half-hour or so of the engine running, the cylinder must have been acting to a certain extent as though it were jacketed, until the jacket got full of water;

and therefore the jacket water ought properly to be debited to the account, though of course it was but a small matter, and as soon as the jacket was full of water it became not a steam jacket but a water jacket.

As to the effect of density of the steam, it was stated in page 648 that all the author's trials, and all others which he had had an opportunity of analyzing, tended most conclusively to show that the initial condensation varied directly as the density of the incoming steam. This was one of the points to which he had himself referred in his own paper in 1888 (Proceedings Inst. C.E., vol. xciii, page 155), and he had made the trials in Table VII (page 183) on purpose to see, if he could, whether that was so or not. The results were plotted from the line HO (Table VII, page 675) by the black dots in Fig. 52, Plate 132, in which it was seen that the density of the steam varied from 0·14 to 0·29. This was probably the most unsatisfactory of all the series of his own trials, because the plotted black dots were here wider apart than in almost any others of them. But when the straight line CC was drawn to represent the condensation at cut-off varying directly as the density, the results of his own trials were seen to be so far removed from this line that he thought the condensation could not be said to vary as the density. The line CC was here drawn starting from the dots on the left, because at the lowest density there were two trials, one checking the other. On the other hand he had then taken the converse cases where the density of the steam did not vary, and had plotted in Fig. 53, Plate 132, both the observed condensation at cut-off as given in his own Table IV (page 673) and shown by the black dots and the average line WW, and also the author's calculated condensation at cut-off as given in Table 10 and shown by the open circles and the average line EE. It was seen that the two appeared to go pretty well together, so far as their general direction went. These diagrams might be wrong, but at any rate one was a curious corroboration of the other; and they could hardly be held to justify the author's inference from them, namely that the initial condensation varied directly as the density of the incoming steam.

He quite agreed with the author's concluding remark that it would be a most useful thing if a formula could be arrived at from

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which it could be ascertained beforehand exactly how much steam was likely to be used in any engine. The probability was, he thought, that there would be very different constants for different kinds of engines; and although it seemed consequently almost impossible to construct any general formula, still any attempt to do so ought to be welcomed. If therefore he criticised any formula in the paper, he hoped he might be regarded as doing so only in the hope, however remote, that some practically useful expression might ultimately be arrived at.

Starting from the author's position that range of temperature had nothing to do with the initial condensation, it could but be expected that very little about range of temperature would be found in the formula. At the bottom of page 652 there was a formula for the weight of steam used per stroke in unjacketed cylinders, of which only the two factors, $\frac{80}{\sqrt{N}}$ and $\frac{S_c - S_1}{L}$, represented the portion that applied to initial condensation. Here the constant 80 was of course only deduced from a series of trials, and N was the number of revolutions per second. This he believed was Professor Cotterill's expression, and he supposed it was quite right: although he thought his own experiments justified the opinion that besides mere surface there were other causes for condensation, which did not follow the same law. Then as to the other factor, S_c was the unjacketed clearance surface, agreeably with the assumption in page 647 that any surface which was jacketed had no effect in causing initial condensation; but although he thought the jacketing of the clearance surface diminished its condensing effect, he did not agree with the author that it eliminated it. From the unjacketed clearance surface S_c was then subtracted the fresh surface S_1 exposed during admission. In regard to this difference $S_c - S_1$ it would be noticed that if S_c equalled S_1 there ought to be no initial condensation whatever; and there must be a large number of engines in which it was the case that the clearance surface S_c did equal the fresh surface S_1 exposed during admission. It therefore seemed to him that the minus sign ought to be plus, changing the difference $S_c - S_1$ into the sum $S_c + S_1$; for he considered the fresh surface S_1 exposed during

admission was as important a factor in the condensation as was the unjacketed clearance surface S_c: the one was just as true a cause of initial condensation as the other: understanding by initial condensation the condensation up to the point at which it could first be accurately measured, namely up to cut-off. To prevent initial condensation it was necessary that both the clearance surface and the fresh surface exposed during admission should be presented to the entering steam at a temperature as little below that of the entering steam as possible. It seemed to him a great pity that the steam condensed in the ports and in the body of the cylinder should be all included in the same formula. There was no difficulty in calculating the steam required to fill the body of the cylinder during the stroke; what was wanted to be ascertained was merely the portion of steam that got condensed at the start, that is, up to the point of cut-off. If the two were mixed, it seemed likely that only an approximate result would be arrived at.

As to the general results of the author's formula, the agreement of his calculations with the speaker's observed results was certainly very close in many of the figures shown in Plates 129 to 131; and it was all the more curious, because in his own engine there was a considerable clearance space, which the author did not appear to know anything about, and which therefore his formula did not cover. There was a considerable amount of steam supplied to fill a passage in the trunk, which had to be filled from the back pressure up to the pressure at cut-off. Hence the agreement between the author's formula and the speaker's results appeared to be much closer than it actually was. The filling up of the clearance space was of course a much more important matter when the pressure was high than when it was low, that is, when the density was higher and more steam was required to fill it; and the omission of this steam, which was not covered by the author's formula, appeared to lend colour to the view that the condensation increased with the density.

Another point he should like to raise was in connection with the remark in page 647 that the jacketed surface had nothing at all to do either with the initial condensation or with the subsequent re-evaporation during the stroke. What then was the good of having

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two formulæ, or rather one formula with two coefficients, one for unjacketed cylinders and the other for jacketed? In the first case a formula was arrived at by eliminating the jacketed surface and treating only of the remaining surface which was unjacketed; and then after doing so this same formula with a change of coefficient was adopted for the jacketed cylinder. In Fig. 2, Plate 119, he observed that the dots denoting the observed results agreed very well with the line JJ calculated for the jacketed cylinder, and yet this particular trial happened to be with the cylinder unjacketed; and the same remark applied also to Fig. 14, Plate 122, and Fig. 22, Plate 124: so that it seemed to him that the formula was only approximate, and that the one coefficient fitted quite as well as the other, irrespective of whether the cylinder was jacketed or not.

In the trials made with air admitted into the cylinder during the exhaust (page 644), for the purpose of seeing whether the initial condensation could thereby be reduced, it was mentioned that this result was obtained, but that the back-pressure was increased. It seemed as though the author had not realised that this experiment amounted in effect to opening an air-cock into the condenser, and to that extent spoiling the vacuum and diminishing the range of temperature. The reference in page 647 to experimental evidence showing that the rate of transmission of heat through a metallic plate depended on the difference of temperature of the media on either side seemed to him not to bear at all on the subject of the paper. Surface condensation and re-evaporation in a cylinder depended on the film of metal exposed to the steam; and this film probably alternated between the higher and lower temperature of the entering and the exhaust steam. It seemed to him impossible to imagine cylinder condensation apart from range of temperature.

Professor James H. Cotterill said the author's formulæ were mainly based on three suppositions: first, that initial condensation would be proportional to the density of the incoming steam (page 648); second, that it did not depend on the range of temperature (page 648); and third, that it was proportional to the area of the surface, and inversely as the square root of the speed (page 647).

With regard to density, it appeared to him that there were conceivable circumstances in which the rate of condensation might vary as the density. If the whole mass of the cylinder were imagined to be at a uniform low temperature, and the steam to be suddenly admitted to it, then the metal would absorb heat with extreme rapidity, and the condensation would probably depend on two things: on the obstruction which was offered to the passage of heat by the film of water condensed upon the surface; and again on the number of particles of steam which could come into contact with the surface in a given time. His own idea was that it would depend mainly on the obstruction which the film of water offered. But if access of the steam to the surface was obstructed sufficiently by contracted passages and a slowly opening slide-valve, condensation might be conceived to vary as the number of particles of steam which were capable of coming into contact with the cylinder surface in a given time: which meant that it would be in proportion to the quantity of steam within a given distance of the surface, and hence to the density of the steam, as the author supposed. But it seemed to him that this was not at all the condition of things in the actual cylinder, which was being alternately heated and cooled. Every particle of the metal was going through a cycle of changes of temperature; and under these circumstances it seemed to him that the condensation must vary as the range of temperature of the metal. Moreover the changes of temperature penetrated the metal to a very short distance, and the absorption of heat was limited by the necessity of giving out the same amount when the temperature fell. Obstructed access to the surface, though not without influence, did not seem to him so important as to cause the condensation to vary as the density of the incoming steam. It might depend on the density of the exhaust steam; but that was a different question. It seemed then that the initial condensation must depend on the range of temperature of the metal; but it did not follow that the range of temperature of the metal was the same as the range of temperature of the steam. Although the temperature of the metal might be approximately the same as that of the steam during admission and during expansion, yet in many cases, and whenever

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there was a wide range of temperature due to a wide difference between the terminal pressure and the exhaust pressure, the temperature of the surface of the metal would not descend to the exhaust temperature. During exhaust the surface of the metal would be dry; and under these circumstances the escape of heat from the dry surface would probably depend on the density of the exhaust steam. No doubt the escape of heat from the dry surface would be comparatively feeble, so that its direct influence would be very small. But indirectly it might have a great influence in another way, by widening the range of temperature of the metal, and so increasing the initial condensation. It was possible to show that the escape of heat from the dry surface during exhaust would have this effect upon the range of temperature of the metal; and where the steam was admitted throughout the entire stroke, it was possible to find a formula for the initial condensation, which in that case would depend partly on the range of temperature and partly on the density of the exhaust steam. Let W = weight in lbs. of steam condensed per revolution per square foot of surface; $t_1 - t_0$ = range of temperature of the steam; L_1 = latent heat of evaporation at the admission temperature; N = revolutions per minute. Then $W = \dfrac{t_1 - t_0}{L_1 \sqrt{\dfrac{N}{B} + \dfrac{t_1 - t_0}{K} N}}$, which determined W in terms of two constants B and K; of these B depended on the conductivity of the metal and the nature of the temperature-cycle, and K depended on the escape of heat from a dry surface per minute per degree of difference of temperature. With regard to speed, the initial condensation would vary in part inversely as the square root of the revolutions, and in part inversely as the revolutions themselves. There was one conceivable case in which the condensation might be supposed to be independent of the range of temperature of the steam, and that was at a high speed when the expansion was not great, that is, when the steam was admitted through nearly the full stroke. Then the formula showed that the initial condensation might be independent of the range of temperature of the steam; but this was the only instance, as it seemed to him, in which such

could be the case. In other cases the initial condensation would depend upon the range of temperature of the steam; but it would not necessarily be directly proportionate to the range of temperature. The formula was of limited application, and the values of the constants uncertain, especially K; but he thought it worth giving, as showing that the theory of the conduction of heat did not necessarily require the supposition that condensation should be proportional to the range of temperature of the steam and inversely to the square root of the speed.

Professor Alexander B. W. Kennedy, Member of Council, said the paper contained the result of an immense amount of work very much elaborated. A question had already been asked (pages 676–7) about the water measurement, and the want of agreement between the two totals in lines i and j in Table 9, where in several cases there seemed to be a wider disagreement than he could understand. His own experience would lead him distinctly to prefer the measurement of the feed-water as it went in; but of course it would be expected that the two measurements would agree fairly well. There were five cases in Table 9 in which they practically did agree within 1 per cent., but there were a number of cases in which they did not; and out of the whole forty-one there were five in which the water measured out exceeded the feed measured in, while in the remaining thirty-six cases the feed measured in was more than the water measured out. It would be interesting to those who were working at engine trials if the author would explain why he preferred the one measurement to the other, and what the actual cause of these serious differences was, because they were so large that it was impossible to pass them over.

As to range of temperature, he presumed that by this expression as used in page 647 of the paper was meant the difference of temperature on the two sides of the cylinder wall; whereas of course the expression was generally understood to mean the range between the highest and lowest temperature of the steam. He could not agree in any way with the author's treatment of the question of temperature; and it certainly did not appear how the difference of temperature

(Professor A. B. W. Kennedy.)
between the two sides of the cylinder wall could have so much more to do with the matter of initial condensation than the working range of temperature had. The assumption also of the absolute mean temperature T_m of the cylinder really seemed almost in the nature of a guess in page 649, where it was taken as approximately equal to the temperature due to the mean forward pressure. Why it should be so, he thought there hardly seemed much reason; because for at least half the time the temperature of the cylinder walls must surely depend more or less—Professor Cotterill had shown (page 688) why it should only depend partially—upon the temperature of the back pressure. No doubt the author would explain his reason for so assuming the absolute mean temperature of the cylinder, as it was not clear on the face of it why he had done so.

In examining Table 10 he was much struck with the fact that under the heading of condensation per stroke the calculated results and the observed results either did not agree or agreed in a very odd fashion; they agreed so little that some explanation seemed to be needed from the author as to why exactly he thought his formulæ thoroughly represented these experiments. For instance, taking No. I, which was a non-jacketed trial, the three observed results (9·3 and 6·3 and 3·4) agreed pretty fairly with those calculated for a jacketed trial (9·1 and 6·3 and 4·9); whereas in No. II, which was also a non-jacketed trial under different conditions, the three observed results (16·0 and 12·7 and 9·2) agreed rather with the calculated results for a non-jacketed trial (18·3 and 12·7 and 9·5). Both being non-jacketed trials, the agreement of the observed results ought in both cases, as far as he understood matters, to be with those calculated for the cylinder as non-jacketed. There were several other instances of that kind; and there were some instances, such as No. VI and No. VIII and others, in which the calculated results did not really agree at all well with any of the observed results. That might possibly be really due to the treatment of temperatures, which as already mentioned he had not been able to make out.

The separation of the cylinder surface into two such very distinct portions appeared to him to want something more of proof;

at any rate it seemed to be empirical in itself, rather than based on any scientific reason. For it did not appear as if the whole cylinder surface, either up to the cut-off or up to the end of the stroke, could quite fairly be divided into two distinct parts, one of which was the clearance surface and the other all the rest. Unless the cylinder surface happened to become so divided in an empirical formula, there did not seem in the absence of proof to be any scientific reason why it should be divided in that particular manner.

It would add he was sure to the ease of reading the paper and Tables if the author would append to them a concise tabular summary, giving just the leading characteristics of each trial. These could of course be found out by going carefully through the present Tables, in which all the information was given in the fullest manner; but he had himself had to go over them in order to mark the various points he had alluded to, and in doing so it had occurred to him that a small synopsis would help a good deal, because no doubt these experiments would be frequently looked at afterwards. (See Table 11 subsequently added, pages 670–1.) It was rather unfortunate that the engine which the author had experimented with had been one that condensed half its steam before it commenced to do any work. It was no doubt interesting to know what it actually did perform; but he hoped there were other engines, that would not behave so badly in this particular, out of which some information could be got on a future occasion.

Mr. J. Macfarlane Gray, instead of accepting the view expressed in pages 647 and 648 of the paper, that range of temperature did not materially affect the amount of initial condensation, had been led to think that this influence might be even greater than in the simple ratio of that range. If the depth of penetration of change of temperature into the cylinder metal varied as the range of temperature, the heat missing per unit of surface up to the point of cut-off would vary as the square of the range of temperature. Although he did not think this was really the case, he had nevertheless thought it worth while, in the present position of the question, to apply this assumption to Mr. Willans' Table I as given in page 672 of the

(Mr. J. Macfarlane Gray.)

present paper. Taking the full range of temperature in each case, the heat units per stroke, missing at cut-off, as calculated by himself on this assumption, were given in the third line HG below, in comparison with the two lines HO and HC, copied from page 672, which represented respectively the heat units missing as actually observed and as calculated by the author:—

HO	3·269	5·166	8·168	7·048	7·863	10·261	9·436
HC	0·8	1·2	3·4	4·2	5·4	6·0	6·7
HG	3·147	4·326	11·948	7·637	9·279	9·980	11·090

He had not been able to get any corroboration of this assumption from the other tabulated results; but he thought that Table I gave the only set of Mr. Willans' experiments here quoted in which range of temperature was not inextricably mixed up with other varying influences. The effect of compression-heating and of piston-leakage might however have contributed to produce the more approximate run of numbers in the line HG here given. The author had started a most important investigation in an eminently practical manner; and if his conclusions were not yet quite satisfactory, this was only because of the problem being extremely complicated and beset with almost insuperable difficulties. The present paper he considered a valuable one for the Institution, and the author deserved the best thanks of the Members.

Mr. G. R. Bodmer drew attention to the opinion expressed in page 647 of the paper, that the effect of the cold portion of the clearance surface in producing condensation must be most marked at the first instant, when the difference of temperature was greatest; and must diminish as the surface was brought up to the same temperature as the steam in contact with it. This seemed to be a clear admission that initial condensation depended upon the difference in temperature between the steam and the metal; but then later on in page 647 the author seemed to contradict it again, by saying that the assumption that the condensation must vary directly as the range of temperature in the cylinder appeared to be based upon a fallacy; and still further on (in page 648) it was added that to say the condensation would depend upon the range of temperature was equivalent to saying that

there would be no condensation at all after the temperature of the inner surface of the cylinder was raised to that of the incoming steam. It was thus apparently admitted that the range of temperature had some influence; and the author proceeded to introduce the ratio of the initial temperature of the steam to the mean temperature of the cylinder metal, though apparently only to eliminate it again by assuming the two to be equal. It would be interesting to know on what ground it could be assumed that, during the period of the steam coming in contact with the clearance surface, the temperature of the incoming steam was equal to the mean temperature of the cylinder metal throughout that period. It seemed to himself almost obvious that the temperature of the metal, during the first instant in which the steam at its initial pressure came in contact with the clearance surface, must be much lower than the temperature of the steam coming in contact with it. The maximum temperature which the clearance surface could attain at the first moment when the steam was admitted could not very well be higher he thought than the temperature due to the pressure of the cushion steam. Probably if the difference between the temperature of the admission steam and the effective mean temperature of the clearance surface, during the period of condensation, was introduced into the calculation, the lower temperature should be something in excess of the temperature of the cushion steam, since after the first instant the metal surface would be rapidly heated up to nearly the temperature of the admission steam. Yet again in page 648 it was said that in a steam cylinder there would be a nearly constant rate of condensation due to conduction through the metal. Even in that case difference of temperature would come in, only it would be the difference between the temperature of the metal of the cylinder and that of the outside atmosphere or jacket; because the rate of conduction must depend, to some extent at any rate, on the difference between the temperature of the metal and that of the outside medium, such as the air.

The hypothesis that range of temperature had a good deal to do with initial condensation was borne out by the principles which were now generally applied to the construction of two-cylinder compound and triple-expansion engines. Such engines were

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proportioned chiefly on the supposition that the range of temperature in each of the cylinders ought to be reduced as much as possible, and to be about equal in each cylinder, with the view of reducing condensation as much as possible; and the results seemed to bear out the accuracy of this hypothesis.

The expressions on pages 652 and 653 for representing the weight of steam condensed during the admission period—namely $\frac{80}{\sqrt{N}}\frac{S_c-S_1}{L}$ and $\frac{56}{\sqrt{N}}\frac{S_c-S_1}{L}$—involving as they did the factor S_1 which denoted the fresh surface uncovered during admission, seemed to him to imply the rather strange assumption that re-evaporation might occur even during the admission period. But he did not see how it was possible to find out practically whether condensation or re-evaporation was really going on during that period; because until the cut-off had taken place it could not be known what weight of steam there was in the cylinder. Assuming that the valve was tight, the weight of steam in the cylinder at the point of cut-off in each stroke could be ascertained from the measurement of the feed-water or of the steam condensed; but at any period antecedent to the cut-off there appeared to him to be no means whatever of knowing how much steam there was in the cylinder, and therefore no conclusions could be drawn as to whether any re-evaporation was going on. It seemed to him indeed impossible that there could be any re-evaporation then, unless there was a very rapid fall in pressure, due to wire-drawing.

For reducing the loss caused by excess of condensation over re-evaporation, one of the three methods proposed in page 655 consisted in increasing the length of the stroke. But even if in that way it were possible, which he believed it was not, to re-evaporate the whole of the steam initially condensed, the advantage so obtained would be comparatively trifling, because the heat would then be re-communicated to the steam under unfavourable conditions, and not in the most effective way. There was one possible method, he thought, of improving the economy of an engine, which seemed not to have been noted by the author, and to which he had observed that not much attention was usually paid: namely by increasing

the amount of compression, that is, increasing the pressure of the cushion steam; by so doing the initial difference of temperature would be reduced, by bringing the temperature of the clearance surface more nearly up to the temperature of the fresh steam entering the cylinder.

Mr. Charles E. Cowper called attention to the high consumption of water per horse-power per hour, which in Table 10 ranged from 25·4 lbs. to 33·8 lbs. It might not be obvious perhaps, to those not accustomed to independent engine trials, what this meant; users of engines thought more about the coal. Dividing these quantities of water by $8\frac{1}{2}$ lbs. of water evaporated per lb. of coal, the coal consumption would be found to vary from 3 lbs. to 4 lbs. per horse-power per hour. In comparison with the economy obtained in good steam-engines of the present day, this consumption involved considerable waste of fuel. It would have afforded useful information he thought if the author, who had closely observed many details in connection with the working of the engine, had pointed out what he considered to be the chief reasons of this waste.

Mr. G. S. Young asked whether the pressure in the jacket was constant, or increased as the pressure increased in the boiler; or whether the steam supplied to the jacket was somewhat reduced in pressure below the boiler pressure. Also were there any means provided to prevent water from passing into the cylinder with the steam, such as a separator fitted in the steam-pipe, close to the cylinder? Assuming that the pressure of steam in the jacket was equal to the pressure in the cylinder, there was such a great deal of condensation attributed to the cylinder that it seemed to him almost impossible for the major part of it to be taking place in the cylinder at all; and he thought the water was going in as water, and was not actually condensed in the cylinder, but part of it was condensed before it came to the cylinder and part had passed from the boiler in the shape of priming water. If saturated steam only was entering the cylinder, it seemed extraordinary that, out of a loss of about 50 per cent. to be accounted for, only about 5 per

(Mr. G. S. Young.)

cent. of condensation was prevented by the use of the steam-jacket; and he thought that from 40 to 50 per cent. of what was put down to condensation in the cylinder should be looked for in some other direction. The use of the steam blast at intervals when required, as mentioned in page 643, he also thought would, by increasing the rate of evaporation in the boiler, increase the amount of priming, and thus probably account for part of the irregularity in the observed results.

Mr. Arthur Paget, Vice-President, drew the attention of the Members to the fact that at all events the present paper and discussion would prove, if it were needful to do so, the wisdom of the Institution in having appointed a Research Committee to study the subject of steam-jacketing. Seeing that engineers who were known authorities on the subject differed so widely in their opinions and conclusions, he thought it was evident that there was a serious necessity for such an investigation, to give the certain knowledge upon this subject which did not seem now to be possessed.

Major English in reply considered that the discrepancies between the total feed-water and the total collected water in lines *i* and *j* in Table 9, referred to by Mr. Willans (page 677) and Professor Kennedy (page 689), were due to the fact that a boiler of this class would vary considerably in internal capacity according to the varying action of the furnace. The results of five separate trials made with this boiler to determine the amount of variation under different conditions of firing were shown in Figs. 54 to 58, Plate 133. In these trials the engine was standing, and no water was introduced into the boiler, which was practically tight, and measurements of the water-level were taken at two gauge-glasses every five minutes. An apparent increase or decrease in the weight of water in the boiler, amounting in some cases to 50 lbs., could be readily obtained with a constant steam pressure by variations in the state of the fire and the damper; and discrepancies due to this cause became larger when, as in his trials, the measurements of the feed-water were begun and ended with the engine in motion.

Mr. Willans had spoken (page 678) of the omission of the heat due to work; but by the method of calculation adopted in the paper this heat was duly accounted for in Table 10. For example, in series III, at the end of the stroke the distribution of heat, calculated as in page 490 of Proceedings 1887, was as follows per lb. of cylinder steam:—

	Thermal units.
Total external work	99
Internal heat remaining in steam and condensed water . .	673
Condensation, or heat abstracted by cylinder	277
Available heat supplied	1049

Multiplying the condensation 277 by 0·035 lb., the weight of steam per stroke, the result was the net observed condensation at the end of the stroke, namely 9·7 thermal units, as given in the bottom line in Table 10.

The question of advantage in increasing the length of the cylinder, referred to by Mr. Willans (page 679), applied to simple engines only, and not to a compound engine, in which, for the reasons given in page 656, the difference between long and short cylinders had much less effect. Mr. Willans's own engine, when worked as a simple engine with a very short stroke and a large range of temperature, certainly showed considerably more condensation than the average of engines of ordinary proportions.

Referring to Mr. Willans's comparison in page 679 of the group of trials No. I, using 33·8 lbs. of water per horse-power per hour, with No. XVII using 25·5 lbs. under similar conditions, it had been pointed out in the paper (page 645) that the results showed that the steam used in group XVII was being sensibly superheated, as it was also in groups IV and VIII, since in each of these cases there was more heat remaining in the steam at the end of the stroke than would, when added to the external work done, correspond with the total heat of the weight of saturated steam at the initial pressure. If this view were accepted, it was clear that the effect of such superheating, though not admitting of definite measurement, must be to increase the efficiency of the steam used.

(Major English.)

As regarded the question of the density of the steam having an effect on the condensation (page 683), he quite agreed that between the observed results plotted in Fig. 52, Plate 132, and the line CC there drawn for the heat units missing at cut-off, there was a wide discrepancy. There might be any number of straight lines representing calculated results, starting from the zero point of the vertical and horizontal scales, and varying as the density; but out of these the dotted line BB was the only one in accordance with his own calculations, which were here plotted by the open circles from the bottom line HC in Table VII, page 675.

Another point which had been raised (page 684) was that, in the case where the additional surface exposed during the stroke was equal to the clearance surface, there ought to be no initial condensation at all. Probably what was meant was no condensation at the point of cut-off; and this had all but occurred in Mr. Willans's triple engine when the additional surface exposed during the stroke approached the clearance surface.

The clearance space in the trunk of Mr. Willans's engine (page 685) he thought would not affect the calculated figures in Table 12 and Plates 129 to 131, since the weight of steam accounted for by indicator at cut-off was deduced directly from Mr. Willans's own tables, in which the steam required to fill this clearance space would necessarily be included.

The fact had apparently been overlooked by Mr. Willans (page 686) that the difference between the complete formulæ in page 651, for net condensation in jacketed and unjacketed cylinders, was more than a change in the constant; and that, so far as these formulæ represented the facts, the varying temperatures of the inner surface of the cylinder would have more effect in increasing the initial condensation and diminishing the re-evaporation in an unjacketed than in a jacketed cylinder.

The air-cock placed on the cylinder (page 686), in order to see whether the admission of air would affect the initial condensation, had been fixed so that any air passing through it must necessarily pass over the internal surface of the cylinder before going on to the condenser.

In reply to Professor Cotterill (page 687), he would venture to recall attention to the conclusion set forth in page 646 of the paper, that the initial condensation was extremely sudden—so sudden in his opinion as to be practically instantaneous in comparison with any present means of measuring its rate. Unless this conclusion was agreed to, he was quite prepared to admit that there would be no solid foundation for the formulæ which he had suggested; but if all or any large proportion of the action of condensation took place in an interval of time too short to allow the quantity of heat necessarily liberated from the steam to be transferred to the interior substance of the metal according to the known laws of conduction, it seemed to him that, whatever the action of condensation might be, it would be independent of any cyclical changes in the temperature of the body of the metal. Initial condensation apparently took place at the highest speeds of revolution yet experimented on: not certainly to the same extent as at slow speeds, but still at a sufficiently appreciable rate; and until some process could be devised for obtaining quantitative results of the time occupied in condensing a given weight of steam brought suddenly into contact with a comparatively cold metallic surface, it seemed to him hardly practicable to do more than connect the amount of condensation with the mean temperature of the metal and the known temperature of the steam; and this was what he had attempted to do in the formulæ.

Replying to Professor Kennedy (page 690), the reason why the mean temperature of the cylinder had been taken at page 649 as approximating to that due to the mean forward pressure only of the steam was stated in page 650, to the effect that the surface of the cylinder during the exhaust was probably dry; and he was glad to find that Professor Cotterill concurred in this view. It seemed to him to follow therefrom that practically no cooling effect on the metal of the cylinder would be produced by re-evaporation during the exhaust stroke; and that the re-evaporation induced by the opening of the exhaust port took place as suddenly as the initial condensation.

Referring to Professor Kennedy's criticism (page 689) regarding the use of the expression "range of temperature," what he had

(Major English.)
attempted to show in page 647 of the paper was that the only experimental evidence in favour of condensation being directly proportional to range of temperature was derived from Forbes' results, which led to the commonly used formula—Flow of heat $= \text{constant} \times \frac{t_A - t_B}{y}$, where t_A and t_B were the temperatures of the media on either side of a metallic plate of thickness y. Although no doubt by the expression "range of temperature" was generally understood the range between the highest and lowest temperatures of the steam during a stroke, he thought it was usually taken for granted that in some way or other the formula just quoted would apply to a steam cylinder; and it was to this view that he himself took exception. It was certain at any rate that if the various trials made by the U.S. Navy in 1874–5, and by Mr. Willans, and by himself, were taken as a whole, the observed condensation, either near the point of cut-off or at the end of the stroke, showed no indication of being in any way proportional to the range between the highest and lowest temperatures of the steam. Much less would they agree with Mr. Macfarlane Gray's view (page 691) that the condensation should vary as the square of the range of temperature.

To Professor Kennedy's question (page 690) as to why in some cases the observed results in a non-jacketed trial agreed with the formula for a jacketed cylinder, he would reply that he did not consider any of the trials to be absolutely non-jacketed. The jacket steam was taken direct from the boiler to the cylinder casting, which formed the bottom of the smoke-box, and there was no possibility of shutting off the communication; the only way of stopping the passage of steam through the jacket was by shutting the drain-cock, but steam from the boiler could still enter the jacket freely; and the high temperature of the smoke-box had in some cases an unmistakable effect. For these reasons he had drawn two curves, representing condensation according to the formulæ for both jacketed and unjacketed cylinders, in all the diagrams relating to groups in which the jacket drain-cock was shut, except in groups IV, VIII, and XVII, where the steam was manifestly superheated; and he was obliged to leave the comparison of the observed results to be made

with one curve or the other according to opinion. It was certainly unfortunate that more definite results could not be obtained on this point; but it was impossible for that to be done without undesirable structural alterations to the engine and boiler.

As to the division of the surfaces into clearance surface and stroke surface (page 691) being empirical, the empiricism appeared to him to depend on whether it was considered that the condensation was extremely sudden and took place during the time when the clearance surface only was exposed, or whether it was considered that it lasted during the stroke. If it took place only, or in far greater part, at the commencement of the stroke, a natural division of the two portions of the surface would thereby be defined.

In Table 11 he had much pleasure in submitting the short synopsis asked for (page 691), so as to do the best he could for making the paper fully intelligible.

Replying to Mr. Bodmer (page 693), it was intended to be implied in page 648 that the temperature of the incoming steam was equal to the mean temperature of the cylinder metal throughout the stroke, only in the case when the cylinder was kept continuously at the temperature of the steam, by preventing the flow of heat through it outwards, and by creating a flow inwards either by thoroughly efficient jacketing or by superheating. It was only in this case that he thought the effect of range of temperature on the initial condensation would become negligible. The hypothesis, and of course it could be no more than a supposition, that re-evaporation occurred during the admission portion of the stroke (page 694), was absolutely necessary to the train of reasoning in the paper. It certainly could not be directly verified; but according to all observations made by himself, excess of re-evaporation over condensation was going on at a rate at least as rapid immediately after the cut-off as later in the stroke; and it seemed to him that the conclusion thence to be drawn was that this excess was also going on before the cut-off.

Replying to Mr. Young (page 695), the only check possible upon priming water in this engine lay in the rate of evaporation per pound of coal, which had been very satisfactorily consistent in all cases.

(Major English.)

As to the pressure in the jacket (page 695), he had already explained that the jacket was in direct communication with the boiler, and carried the boiler pressure in all cases: it was impossible to prevent its doing so.

The PRESIDENT said a doubt had been expressed as to what was the meaning of the range of temperature alluded to in page 647: whether the author simply meant variation in the temperature of the cylinder metal, or whether he alluded to the range of temperature in the steam itself within the cylinder.

Major ENGLISH said that in speaking of range of temperature he was alluding to the temperature of the inner surface of the cylinder metal. As to the character of an engine which required 3 lbs. or 4 lbs. of coal per indicated horse-power per hour (page 695), he did not feel it at all necessary to defend the engine itself, the makers themselves being well able to do so; but he would take the opportunity of recording his opinion that it was capable of working more economically than the average of engines of its class.

The PRESIDENT said he had been anticipated by Mr. Paget's happy allusion to the appointment of the Research Committee on the value of the steam-jacket. An investigation of this subject was evidently most desirable; for there were many points on which in the present discussion such varied opinions had been expressed, that it was time an attempt should be made to see whether they could be reduced to law and order. The Members were much indebted to Major English for bringing before them his experiments, which represented a vast amount of labour. The interesting discussion which had followed the reading of the paper was evidence that it had been thoroughly appreciated; and he was sure that the meeting would pass a hearty vote of thanks to the author for having prepared the paper and brought it before the Institution.

FIRST REPORT OF THE RESEARCH COMMITTEE ON THE VALUE OF THE STEAM-JACKET.

Tabulated Results of previous Experiments.

The Research Committee appointed by the Council at the end of 1886 to investigate the value of the Steam-Jacket, before entering upon any fresh experiments, endeavoured as their first step to ascertain what had already been published upon this subject. For convenience of easy reference and comparison the results of former experiments were then systematically collated by the kindness of Mr. Bryan Donkin, Jun., according to a plan arranged by himself in conjunction with the Chairman of the Committee. These results, which are recorded in conformity with that plan in the following Tables 1 to 33, are divided into three groups, according as they have been derived from single-cylinder non-condensing or condensing engines or from compound condensing engines; in each group the experiments are arranged chronologically, as far as practicable. In tabulating results derived from so many and such varied sources, it has not always been found possible to collate data of precisely the same kind; in some such cases the information originally published has here been supplemented by further particulars kindly furnished for the purpose by the authorities quoted. For almost all these Tables however the essential figures have fortunately been accessible; and the ultimate results are given as far as possible in saving of feed-water per indicated horse-power by the use of the steam-jacket. The experiments only are recorded which have been made in each case both with and without steam in the jackets of the same engine.

In Table 34 is recorded an elaborate series of experiments specially made by Professor Kennedy for contribution to this research.

It will be observed that there is a great variation in the results recorded; this is necessarily the case because of the greatly varying conditions of the different experiments.

Henry Davey, *Chairman.*

INDEX TO EXPERIMENTS.

SINGLE-CYLINDER NON-CONDENSING ENGINES.

SINGLE-CYLINDER CONDENSING ENGINES.

COMPOUND CONDENSING ENGINES.

SINGLE-CYLINDER NON-CONDENSING ENGINES.

No. 1. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Non-Condensing Engine. 120 H.P. Experiments made in 1846 by Messrs. Thomas and Laurens. (Cours de Machine-à-Vapeur, par M. Thomas, Paris.)

Jackets, *With* or *Without* Steam	**With**
Results. Feed-Water, percentage less with steam in jackets	**8 to 10** p.c.

No. 2. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Non-Condensing Engine. *Cylinder* 2 inches diameter, 8 inches stroke. Experiments made in 1859 by Mr. Gordon M'Kay. Steam-supply to jacket by separate pipe. (Journal of Franklin Institute, vol. 37, 1859.)

Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of experiment	hours	8	8
Boiler Pressure, lbs. per square inch above atm.	lbs.	115	115
Revolutions per minute	revs.	203	203
Piston Speed, feet per minute	feet	271	271
Results. Jacket-Water, lbs. per hour	lbs.	..	1·96
„ „ in p.c. of feed-water	p.c.	..	3·2
Feed-Water, lbs. per hour	lbs.	78·75	60·62
„ percentage less with steam in jackets		..	**23·0** p.c.

Single-Cylinder Non-Condensing Engines (continued).

No. 3. *Record of six Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Non-Condensing Beam Engine. *Cylinder* $7\frac{5}{16}$ inches diameter, $26\frac{1}{8}$ inches stroke; only the body and bottom end were jacketed. Experiments made at Bermondsey in 1874 by Messrs. Farey and B. Donkin, Jun. Whole steam-supply to cylinder passed through the jackets when in use.

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	4·5	4·5
Number of diagrams taken		38	38
Boiler Pressure, lbs. per square inch above atm.	lbs.	45	45
Number of Expansions		2·7	2·7
Revolutions per minute	revs.	44·8	48·3
Piston Speed, feet per minute	feet	195	210
Results. Indicated horse-power	I.H.P.	4·94	6·41
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	8·32
„ „ in percentage of feed-water	p.c.	..	14·8
Feed-Water, lbs. per I.H.P. per hour	lbs.	71·69	56·35
„ percentage less with steam in jackets		..	**21·4** p.c.
Duration of experiment	hours	2·75	2·75
Number of diagrams taken		22	22
Boiler Pressure, lbs. per square inch above atm.	lbs.	45	45
Number of Expansions		1	1
Revolutions per minute	revs.	46·8	51·2
Piston Speed, feet per minute	feet	204	223
Results. Indicated horse-power	I.H.P.	8·90	10·57
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	4·51
„ „ in percentage of feed-water	p.c.	..	8·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	62·51	53·18
„ percentage less with steam in jackets		..	**14·9** p.c.
Duration of experiment	hours	3	3
Number of diagrams taken		24	26
Boiler Pressure, lbs. per square inch above atm.	lbs.	45	45
Number of Expansions		1	1
Revolutions per minute	revs.	47	45·6
Piston Speed, feet per minute	feet	205	199
Results. Indicated horse-power	I.H.P.	5·04	4·52
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	10·4
„ „ in percentage of feed-water	p.c.	..	14
Feed-Water, lbs. per I.H.P. per hour	lbs.	83·28	74·04
„ percentage less with steam in jackets		..	**11·1** p.c.

Single-Cylinder Non-Condensing Engines (continued).

No. 4. *Record of four Experiments on the same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Non-Condensing Corliss Engine. Experiments made at Lille, France, in 1874, by M. Cornut. (Bulletin de l'Association des Appareils-à-Vapeur, Nord de France, 1876.)

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	days	2	2
Number of Expansions		18 to 21	18 to 21
Results. Indicated horse-power	I.H.P.	78·9	78·9
Feed-Water, lbs. per I.H.P. per hour	lbs.	23·87	19·21
„ percentage less with steam in jackets		..	**19·5** p.c.
Number of expansions		7 to 8	7 to 8
Results. Indicated horse-power	I.H.P.	136	136
Feed-Water, lbs. per I.H.P. per hour	lbs.	21·25	18·32
„ percentage less with steam in jackets		..	**13·8** p.c.

No. 5. *Record of two Experiments on the same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Non-Condensing Ingliss Engine. Experiments made at Lille, France, in 1874, by M. Cornut. (Bulletin de l'Association des Appareils-à-Vapeur, Nord de France, 1876.)

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	days	1	1
Two diagrams taken every 15 minutes		..	..
Number of Expansions		10	10
Results. Feed-Water lbs. per I.H.P. per hour	lbs.	32·0	25·88
„ p.c. less with steam in jackets		..	**19·1** p.c.

Single-Cylinder Non-Condensing Engines (continued).

No. 6. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

SINGLE-CYLINDER NON-CONDENSING DIRECT-ACTING VERTICAL MARINE ENGINE. *Cylinder* 34·1 inches diameter, 30 inches stroke; the body and both ends were jacketed. Experiments made on s.s. "Gallatin" at moorings, in 1875, by Messrs. C. H. Loring and C. E. Emery of the U.S. Navy. The jackets were supplied from the bottom of the steam-chest. The jacket-water condensed in steam-chest and jackets was drained to intermediate vessel fitted with a glass water-gauge and blown off occasionally. (United States Official Reports.) This is the same engine as for the set of experiments No. 18, but here used without the condenser.

Jackets, *With* or *Without* Steam		Without	With
Duration of each of 2 trials	hours	2·2	2·1
Boiler Pressure, lbs. per sq. in. above atm.	lbs.	68·5	68·5
Number of Expansions		4·4 & 3·5	4·1 & 3·5
Revolutions per minute	revs.	46·7 & 51·7	49·5 & 53·2
Piston Speeds, feet per minute	feet	233 & 258	247 & 266·
Results. Indicated horse-power	I.H.P.	170 & 205	190 & 212
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·74 & 0·96
,, ,, in percentage of feed water	p.c.	..	2·9 & 3·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	29·66	26·61
,, p.c. less with steam in jackets		..	**10·3** p.c.

See also set of Experiments No. 18.

Single-Cylinder Non-Condensing Engines (continued).

No. 7. *Record of twelve Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Non-condensing Locomotive Engine. *Cylinder* 16·54 inches diameter, 23·62 inches stroke; one cylinder disconnected from driving axle. Experiments made at Kieff, Russia, in 1881 to 1883, by M. Borodin. Steam-supply to jackets by separate pipe, jackets drained by automatic traps on expansion principle. (Institution of Mechanical Engineers, 1886.)

Jackets, *With* or *Without* Steam		Without	With
Duration of each of 2 trials	hours	3·7 & 1·7	3·5
Boiler Pressure, lbs. per square inch above atm.	lbs.	65·5	63·1
Number of Expansions		3·4	3·4
Revolutions per minute	revs.	99·1	101·7
Piston Speed, feet per minute	feet	390	400
Results. Indicated horse-power	I.H.P.	55·7	59·1
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·7
,, ,, in percentage of feed-water	p.c.	..	2·3
Feed-water, lbs. per I.H.P. per hour	lbs.	33·34	30·24
,, percentage less with steam in jackets		..	**9·3** p.c.

Jackets, *With* or *Without* Steam		Without	With
Dur. of each of 3 trials *without*, and 5 *with* jackets,	hrs.	1·4 to 3·5	1·7 to 3·6
Boiler Pressure, lbs. per square inch above atm.	lbs.	57·3	58·9
Number of Expansions		3·3	3·3
Revolutions per minute	revs.	101	100·4
Piston Speed, feet per minute	feet	398	395
Results. Indicated horse-power	I.H.P.	54·2	55·4
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·67
,, ,, in percentage of feed-water	p.c.	..	2·3
Feed-Water, lbs. per I.H.P. per hour	lbs.	31·48	29·20
,, percentage less with steam in jackets		..	**7·25** p.c.

Duration of each of 2 trials	hours	2 & 3	2·5 & 3·5
Boiler Pressure, lbs. per square inch above atm.	lbs.	54·9	55·4
Number of Expansions		3·3	3·4
Revolutions per minute	revs.	94	101·3
Piston Speed, feet per minute	feet	370	399
Results. Indicated horse-power	I.H.P.	44·6	48·1
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·77
,, ,, in percentage of feed-water	p.c.	..	2·7
Feed-Water, lbs. per I.H.P. per hour	lbs.	33·90	28·38
,, percentage less with steam in jackets		..	**16·3** p.c.

(*Continued on next page.*)

Single-Cylinder Non-Condensing Engines (continued).

No. 7 (*continued from preceding page*).

Dur. of each of 7 trials *without*, and 5 *with* jackets,	hrs.	1·9 to 3·5	1·9 to 3·6
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·5	49·9
Number of Expansions		3·4	3·4
Revolutions per minute	revs.	95	94·4
Piston Speed, feet per minute	feet	374	372
Results. Indicated horse-power	I.H.P.	40·0	40·6
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	1·01
,, ,, in percentage of feed-water	p.c.	..	3·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	34·39	28·94
,, percentage less with steam in jackets		..	**15·9 p.c.**
Dur. of each of 2 trials *without*, and 1 *with* jackets,	hrs.	1·6 & 3	2·2
Boiler Pressure, lbs. per square inch above atm.	lbs.	76·5	77·8
Number of Expansions		5·1	5·1
Revolutions per minute	revs.	93·0	93·1
Piston Speed, feet per minute	feet	366	367
Results. Indicated horse-power	I.H.P.	46·6	49·8
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·91
,, ,, in percentage of feed-water	p.c.	..	3·2
Feed-water, lbs. per I.H.P. per hour	lbs.	31·55	28·53
,, percentage less with steam in jackets		..	**9·6 p.c.**
Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of each of 2 trials	hours	1·9 & 3·3	1·9 & 3·4
Boiler Pressure, lbs. per square inch above atm.	lbs.	75·3	77·9
Number of Expansions		5·1	5·1
Revolutions per minute	revs.	91·9	93·7
Piston Speed, feet per minute	feet	362	369
Results. Indicated horse-power	I.H.P.	45·7	53·5
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·85
,, ,, in percentage of feed-water	p.c.	..	3·36
Feed-Water, lbs. per I.H.P. per hour	lbs.	32·77	25·44
,, percentage less with steam in jackets		..	**22·4 p.c.**

Single-Cylinder Non-Condensing Engines (continued).

No. 8. *Record of twenty-four Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Non-condensing Corliss Engine. *Cylinder* 21·65 inches diameter, 43·31 inches stroke; the body only was jacketed. Experiments made at the Creusot Works, France, in 1883, by M. Delafond. The jackets were supplied with steam by a small pipe from the main steam-pipe, and were automatically drained. (Annales des Mines, 1884, and L'Ingénieur-Conseil, 1885.)

This is the same engine as for the set of experiments No. 23, but here used without the condenser.

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	1·3	1·3
Number of diagrams taken		30	32
Boiler Pressure, lbs. per square inch above atm.	lbs.	110	110
Number of Expansions		6·2	7·1
Revolutions per minute	revs.	61·7	60·8
Piston Speed, feet per minute	feet	445	439
Results. Indicated horse-power	I.H.P.	147·5	143
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·57
,, ,, in percentage of feed-water	p.c.	..	2·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	28·38	22·80
,, percentage less with steam in jackets		..	19·7 p.c.

(*Continued to page* 714.)

Single-Cylinder Non-Condensing Engines (continued).

No. 8 (*continued from preceding page*).

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	1·3	1
Number of diagrams taken		30	24
Boiler Pressure, lbs. per square inch above atm.	lbs.	110	110
Number of Expansions		6·2	6·2
Revolutions per minute	revs.	61·7	62
Piston Speed, feet per minute	feet	445	447·5
Results. Indicated horse-power	I.H.P.	147·5	177·5
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·75
,, ,, in percentage of feed-water	p.c.	..	3·4
Feed-Water, lbs. per I.H.P. per hour	lbs.	28·38	22·13
,, percentage less with steam in jackets		..	**22·0** p.c.
Duration of experiment	hours	0·9	0·6
Number of diagrams taken		22	14
Boiler Pressure, lbs. per square inch above atm.	lbs.	110	110
Number of Expansions		5	5·3
Revolutions per minute	revs.	61·4	62
Piston Speed, feet per minute	feet	443	447·5
Results. Indicated horse-power	I.H.P.	181·5	194
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·69
,, ,, in percentage of feed-water	p.c.	..	3·1
Feed-Water, lbs. per I.H.P. per hour	lbs.	26·82	22·35
,, percentage less with steam in jackets		..	**16·7** p.c.
Duration of experiment	hours	0·4	0·5
Number of diagrams taken		10	12
Boiler Pressure, lbs. per square inch above atm.	lbs.	110	110
Number of Expansions		4·4	4·4
Revolutions per minute	revs.	63·6	62·7
Piston Speed, feet per minute	feet	459	453
Results. Indicated horse-power	I.H.P.	217	237
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·43
,, ,, in percentage of feed-water	p.c.	..	2·0
Feed-Water, lbs. per I.H.P. per hour	lbs.	25·81	21·50
,, percentage less with steam in jackets		..	**16·7** p.c.
Duration of experiment	hours	1·1	1·2
Number of diagrams taken		26	28
Boiler Pressure, lbs. per square inch above atm.	lbs.	78·2	78·2
Number of Expansions		5·4	5·1
Revolutions per minute	revs.	62	61·1
Piston Speed, feet per minute	feet	447·5	441
Results. Indicated horse-power	I.H.P.	121	137
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·4
,, ,, in percentage of feed-water	p.c.	..	1·7
Feed-Water, lbs. per I.H.P. per hour	lbs.	27·58	23·65
,, percentage less with steam in jackets		..	**14·25** p.c.

(*Continued on next page.*)

Single-Cylinder Non-Condensing Engines (continued).

No. 8 (*continued from preceding page*).

Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of experiment	hours	1	1·2
Number of diagrams taken		24	28
Boiler Pressure, lbs. per square inch above atm.	lbs.	78·2	78·2
Number of Expansions		4·8	5·1
Revolutions per minute	revs.	60·9	61·1
Piston Speed, feet per minute	feet	440	441
Results. Indicated horse-power	I.H.P.	136	137
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·4
,, ,, in percentage of feed-water	p.c.	..	1·7
Feed-Water, lbs. per I.H.P. per hour	lbs.	26·71	23·65
,, percentage less with steam in jackets		..	**11·46 p.c.**
Duration of experiment	hours	1	0·8
Number of diagrams taken		24	20
Boiler Pressure, lbs. per square inch above atm.	lbs.	78·2	78·2
Number of Expansions		3·7	3·8
Revolutions per minute	revs.	60	61·6
Piston Speed, feet per minute	feet	433	445
Results. Indicated horse-power	I.H.P.	178	180
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·26
,, ,, in percentage of feed-water	p.c.	..	1·2
Feed-Water, lbs. per I.H.P. per hour	lbs.	24·58	21·79
,, percentage less with steam in jackets		..	**11·36 p.c.**
Duration of experiment	hours	0·5	0·5
Number of diagrams taken		12	12
Boiler Pressure, lbs. per square inch above atm.	lbs.	78·2	78·2
Number of Expansions		2·9	3·1
Revolutions per minute	revs.	60·6	60·5
Piston Speed, feet per minute	feet	437	437
Results. Indicated horse-power	I.H.P.	209	204
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·29
,, ,, in percentage of feed-water	p.c.	..	1·3
Feed-Water, lbs. per I.H.P. per hour	lbs.	24·18	21·95
,, percentage less with steam in jackets		..	**9·23 p.c.**
Duration of experiment	hours	1·2	1·2
Number of diagrams taken		28	28
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		3·7	3·9
Revolutions per minute	revs.	61·4	60·5
Piston Speed, feet per minute	feet	443	437
Results. Indicated horse-power	I.H.P.	108	108
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·38
,, ,, in percentage of feed-water	p.c.	..	1·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	27·27	25·30
,, percentage less with steam in jackets		..	**7·21 p.c.**

(*Concluded on next page.*)

Single-Cylinder Non-Condensing Engines (concluded).

No. 8 (*concluded from page* 711).

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	1·2	1
Number of diagrams taken		28	24
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		2·5	2·8
Revolutions per minute	revs.	61·1	60·5
Piston Speed, feet per minute	feet	441	437
Results. Indicated horse-power	I.H.P.	147	141·5
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·28
,, ,, in percentage of feed-water	p.c.	..	1·1
Feed-Water, lbs. per I.H.P. per hour	lbs.	27·20	25·21
,, percentage less with steam in jackets		..	**7·32** p.c.
Duration of experiment	hours	0·8	0·8
Number of diagrams taken		20	20
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		1·7	1·7
Revolutions per minute	revs.	60·9	60·3
Piston Speed, feet per minute	feet	440	435
Results. Indicated horse-power	I.H.P.	173	168·5
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·2
,, ,, in percentage of feed-water	p.c.	..	0·7
Feed-Water, lbs. per I.H.P. per hour	lbs.	30·17	28·74
,, percentage less with steam in jackets		..	**4·74** p.c.
Duration of experiment	hours	0·4	0·5
Number of diagrams taken		10	12
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		1	1
Revolutions per minute	revs.	60·6	61·1
Piston Speed, feet per minute	feet	437	441
Results. Indicated horse-power	I.H.P.	145	147·5
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·12
,, ,, in percentage of feed-water	p.c.	..	0·26
Feed-Water, lbs. per I.H.P. per hour	lbs.	46·82	46·26
,, percentage less with steam in jackets		..	**1·19** p.c.

End of Experiments on Single-Cylinder Non-Condensing Engines.

For Experiments on Single-cylinder Condensing Engines see next page.

SINGLE-CYLINDER CONDENSING ENGINES.

No. 9. *Record of two Experiments on the same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Engine. 16 H.P. Experiments made in France in 1842, by Messrs. Thomas and Laurens. (Cours de Machine-à-Vapeur, par M. Thomas.)

Jackets, *With* or *Without* Steam	Without	With
Boiler Pressure, lbs. per square inch above atm. lbs.	53	53
Number of Expansions	6	6
Results. Feed-Water, p.c. less with steam in jackets	..	30 to 32 p.c.

No. 10. *Record of three Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Engine. *Cylinder* 15·35 inches diameter, 31·50 inches stroke. Experiments made in Paris in April 1843, by M. Combes. (Académie des Sciences, Paris.) Whole steam supply to cylinder passed through the jackets when in use, except in last column when jackets were supplied with steam by a small pipe only.

Jackets, *With* or *Without* Steam	Without	With	Small pipe.
Duration of experiment hours	33·3	43·2	32·3
Boiler Pressure, lbs. per sq. in. above atm. lbs.	50 to 58	50 to 58	50 to 58
Number of Expansions	20	20	20
Results. Indicated horse-power I.H.P.	6 to 7	6 to 7	6 to 7
Jacket-Water, lbs. per I.H.P. per hour lbs.	..	2·97	4·34
,, ,, in p.c. of feed-water p.c.	..	10	11·75
Feed-Water, lbs. per I.H.P. per hour lbs.	50·9	29·7	36·9
,, p.c. less with steam in jackets	..	41·7 p.c.	27·5 p.c.

Single-Cylinder Condensing Engines (continued).

No. 11. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Vertical Experimental Engine. *Cylinder* 5·25 inches diameter, 10 inches stroke; the body, both ends, and the valve-chest were jacketed. The steam from boiler passed direct to the jackets, thence to the throttle-valve and steam-chest. Experiments made in New York in 1860 by Mr. Isherwood. (Isherwood's Steam Engineering, 1863, vol. 1.)

Jackets, *With* or *Without* Steam		Without	With
Duration of each of 2 trials	hours	60 & 30	60 & 30
Boiler Pressure, lbs. per square inch above atm.	lbs.	55·7	38·2
Number of Expansions		5·3	5·3
Revolutions per minute	revs.	60·1	61·4
Piston Speed, feet per minute	feet	100	102
Results. Indicated horse-power	I.H.P.	0·93	1·13
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	12·76
" " in percentage of feed-water	p.c.	..	23·35
Feed-Water, lbs. per I.H.P. per hour	lbs.	79·38	54·63
" percentage less with steam in jackets		..	**31·2** p.c.

No. 12. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Beam Engine. *Cylinder* 90 inches diameter, 117 inches stroke; only the body was jacketed. Experiments made at Brooklyn Water Works in 1860 by Mr. Isherwood. (Isherwood's Steam Engineering, 1863, vol. 1.)

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	43	42
Boiler Pressure, lbs. per square inch above atm.	lbs.	12	12
Number of Expansions		1·7	1·7
Revolutions per minute	revs.	7·88	8·09
Piston Speed, feet per minute	feet	154	158
Results. Indicated horse-power	I.H.P.	352	361
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·60
" " in percentage of feed water	p.c.	..	1·7
Feed-Water, lbs. per I.H.P. per hour	lbs.	36·37	35·39
" percentage less with steam in jackets		..	**2·7** p.c.

Single-Cylinder Condensing Engines (continued).

No. 13. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Cornish Bull Pumping Engine. *Cylinder* 70 inches diameter, 110 inches average stroke; the body only was jacketed. Experiments made in February 1870 by Mr. Bryan Donkin, Jun. Steam-supply to jacket by separate small pipe.

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	3	3
Number of diagrams taken		10	8
Boiler Pressure, lbs. per square inch above atm.	lbs.	36	36
Number of Expansions		4	4
Strokes per minute, single		11·9	12
Piston Speed, feet per minute	feet	109	111
Results. Indicated horse-power	I.H.P.	153	161
Thermal Units rejected per I.H.P. per minute	Th.U.	493	429
„ percentage less with steam in jackets		..	**12·9** p.c.

No. 14. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Beam Engine. *Cylinder* $7\frac{5}{16}$ inches diameter, $26\frac{1}{8}$ inches stroke; only the body and bottom end were jacketed. Experiments made at Bermondsey in 1870 by Messrs. Farey and B. Donkin, Jun. Whole steam-supply to cylinders passed through the jackets when in use.

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	3	3
Number of diagrams taken		26	26
Boiler Pressure, lbs. per square inch above atm.	lbs.	45	45
Number of Expansions		1·8	1·8
Revolutions per minute	revs.	37·2	39·8
Piston Speed, feet per minute	feet	162	173
Results. Indicated horse-power	I.H.P.	7·71	9·33
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	7·72
„ „ in percentage of feed-water	p.c.	..	17·2
Feed-Water, lbs. per I.H.P. per hour	lbs.	55·54	44·76
„ percentage less with steam in jackets		..	**19·4** p.c.

Single-Cylinder Condensing Engines (continued).

No. 15. *Record of two Experiments on similar Engines* WITH *and* WITHOUT *Jackets.*

SINGLE-CYLINDER CONDENSING CORLISS ENGINE. *Cylinder* $20\frac{1}{16}$ inches diameter, $41\frac{3}{4}$ inches stroke. Experiments made in 1873 by Messrs. Hirn and Hallauer. (Société Industrielle de Mulhouse, 1873, vol. xliii.)

Jackets, *With* or *Without* Steam		Without	With
Boiler Pressure, lbs. per square inch above atm.	lbs.	80	80
Number of Expansions		10	10
Revolutions per minute	revs.	55	55
Piston Speed, feet per minute	feet	383	383
Results. Indicated horse-power	I.H.P.	56·3	83·1
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·68
„ „ in percentage of feed-water	p.c.	..	3·8
Feed-Water, lbs. per I.H.P. per hour	lbs.	23·6	18·0
„ percentage less with steam in jackets		..	**23·7 p.c.**

No. 16. *Record of four Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

SINGLE-CYLINDER CONDENSING BEAM ENGINE. *Cylinder* 26 inches diameter, 30 inches stroke. Experiments made in 1873 by Mr. G. B. Rennie. (Institution of Civil Engineers, vol. li, 1877.) Steam-supply to jackets by separate small pipe.

Jackets, *With* or *Without* Steam		Without	With
Duration of each of 2 trials	hours	48	48 & 49
Boiler Pressure, lbs. per square inch above atm.	lbs.	17	17
Number of Expansions		3·4	3·4
Revolutions per minute	revs.	36·5 to 37·5	36·5 to 37·5
Piston Speed, feet per minute	feet	182 to 188	182 to 188
Results. Indicated horse-power	I.H.P.	39·0	41·6
Jacket-water, in percentage of feed-water	p.c.	..	7·25
Coal, lbs. per I.H.P. per hour	lbs.	4·15	2·81
„ percentage less with steam in jackets		..	**32·4 p.c.**
Duration of each of 2 trials	hours	52·3 & 48	48 & 51
Boiler Pressure, lbs. per square inch above atm.	lbs.	17·2	15·9
Number of Expansions		3·4	3·4
Revolutions per minute	revs.	36·5 to 37·5	36·5 to 37·5
Piston Speed, feet per minute	feet	182 to 188	182 to 188
Results. Indicated horse-power	I.H.P.	39·7	39·6
Jacket-water, in percentage of feed-water	p.c.	..	7·25
Coal, lbs. per I.H.P. per hour	lbs.	4·44	3·05
„ percentage less with steam in jackets		..	**31·3 p.c.**

Single-Cylinder Condensing Engines (continued).

No. 17. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Marine Engine. *Cylinder* 25 inches diameter, 24 inches stroke. Experiments made on s.s. "Bache," at Baltimore, U.S.A., in 1874, by Mr. C. E. Emery. (American Official Reports.) This is the same engine as for the set of experiments No. 29, but here used without the high-pressure cylinder.

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	2·1	2·1
Boiler Pressure, lbs. per square inch above atm.	lbs.	78·1	79·5
Number of Expansions		5·3	5·1
Revolutions per minute	revs.	47·1	53·8
Piston Speed, feet per minute	feet	188	215
Results. Indicated horse-power	I.H.P.	89·1	116
Feed-Water, lbs. per I.H.P. per hour	lbs.	26·25	23·15
,, percentage less with steam in jackets		..	**11·8** p.c.

No. 18. *Record of eight Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Direct-acting Vertical Marine Engine. *Cylinder* 34·1 inches diameter, 30 inches stroke; the body and both ends were jacketed. Experiments made on s.s. "Gallatin," at moorings in 1875, by Messrs. C. H. Loring and C. E. Emery of the U.S. Navy. Jackets supplied from bottom of steam-chest. The jacket-water condensed in steam-chest and jackets was drained to intermediate vessel fitted with glass water-gauge, and was blown off occasionally. (United States Official Reports.) This is the same engine as for the set of experiments No. 6, but here used with the condenser.

(*Continued on next page.*)

Single-Cylinder Condensing Engines (continued).

No. 18 (*continued from preceding page*).

Jackets, *With* or *Without* Steam		Without	With
Duration of each of 2 trials	hours	1·9 & 2·3	2·1
Boiler Pressure, lbs. per square inch above atm.	lbs.	14·6 & 12·8	15·4 & 13·1
Number of Expansions		2 & 1·5	2 & 1·5
Revolutions per minute	revs.	40·1 & 40·9	41·3 & 42·5
Piston Speed, feet per minute	feet	200 & 204	206 & 212
Results. Indicated horse-power	I.H.P.	87 & 90·1	95·3 & 97·9
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·88 & 0·79
,, ,, in percentage of feed-water	p.c.	..	2·6 & 2·1
Feed-Water, lbs. per I.H.P. per hour	lbs.	42·27	35·37
,, percentage less with steam in jackets		..	**16·3** p.c.
Dur. of each of 6 trials *without* and 8 *with* jackets,	hrs.	1·8 to 2·3	2 to 3·8
Boiler Pressure, lbs. per square inch above atm.	lbs.	44·7 to 37·7	45·4 to 36·2
Number of Expansions		5·9 to 2·2	6·1 to 2·2
Revolutions per minute	revs.	43 to 55·8	44·3 to 58·2
Piston Speed, feet per minute	feet	215 to 279	221 to 291
Results. Indicated horse-power	I.H.P.	123 to 237	121 to 255
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	2·1 to 0·49
,, ,, in percentage of feed-water	p.c.	..	9·2 to 1·9
Feed-Water, lbs. per I.H.P. per hour	lbs.	25·94	24·36
,, percentage less with steam in jackets		..	**6·1** p.c.
Dur. of each of 4 trials *without* and 5 *with* jackets,	hrs.	2 to 2·2	2 to 4·4
Boiler Pressure, lbs. per square inch above atm.	lbs.	71·5 to 61·1	71·6 to 67·2
Number of Expansions		7·8 to 4·2	7·3 to 4·2
Revolutions per minute	revs.	52·4 to 59·9	51·1 to 68·7
Piston Speed, feet per minute	feet	262 to 300	255 to 343
Results. Indicated horse-power	I.H.P.	185 to 283	197 to 348
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	1 to 0·6
,, ,, in percentage of feed-water	p.c.	..	5·1 to 2·9
Feed-Water, lbs. per I.H.P. per hour	lbs.	23·67	20·94
,, percentage less with steam in jackets		..	**11·5** p.c.
Duration of experiment	hours	24	24
Boiler Pressure, lbs. per square inch above atm.	lbs.	64·1	65·4
Number of Expansions		4·5	4·5
Revolutions per minute	revs.	60·5	61·5
Piston Speed, feet per minute	feet	302	307
Results. Indicated horse-power	I.H.P.	269	282
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·76
,, ,, in percentage of feed-water	p.c.	..	3·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	24·35	22·04
,, percentage less with steam in jackets		..	**9·5** p.c.

See also set of Experiments No. 6.

Single-Cylinder Condensing Engines (continued).

No. 19. *Record of four Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

SINGLE-CYLINDER CONDENSING CORLISS ENGINE. *Cylinder* 24 inches diameter, 48 inches stroke; the body and both ends were jacketed. Experiments made at Messrs. Schlumberger's Cotton Mill, Mulhouse, in 1878, by M.M. Walther Meunier and G. Keller. Steam-supply to jackets by small pipe. (Société Industrielle de Mulhouse, vol. xlviii, 1878. Institution of Civil Engineers, vol. lviii, 1879.)

The engine used in these experiments had two cylinders, one of which was tested while the other kept the speed constant. The piston was hollow, and was arranged so that it could be filled with steam, with exit for condensed water, but no steam was admitted to the interior during any of the four experiments here tabulated. The economy in consumption of feed-water, due to jacketing the piston only, ranged in several experiments from 2·2 to 2·4 per cent.; in one it was as much as 5·6 per cent.

Jackets, *With* or *Without* Steam		Without	With
Duration of each of 2 trials	hours	10·7 & 5·7	10·7
Boiler Pressure, lbs. per square inch above atm.	lbs.	66·7	67·2
Number of Expansions		5·7	5·7
Revolutions per minute	revs.	49·2	50
Piston Speed, feet per minute	feet	394	400
Results. Indicated horse-power	I.H.P.	128	158
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·67
„ „ in percentage of feed-water	p.c.	..	3·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	24·76	19·45
„ percentage less with steam in jackets		..	**21·5** p.c.
Duration of experiment	hours	5·7	5·1
Boiler Pressure, lbs. per square inch above atm.	lbs.	67·7	68·1
Number of Expansions		12·4	12·4
Revolutions per minute	revs.	49·9	50·4
Piston Speed, feet per minute	feet	400	403
Results. Indicated horse-power	I.H.P.	81·1	100·3
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·91
„ „ in percentage of feed-water	p.c.	..	4·8
Feed-Water, lbs. per I.H.P. per hour	lbs.	27·20	18·97
„ percentage less with steam in jackets		..	**30·3** p.c.

Single-Cylinder Condensing Engines (continued).

No. 20. *Record of two Experiments on same Engine*
WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Horizontal Engine. *Cylinder* 30 inches diameter, 42 inches stroke; body and both ends of cylinder were jacketed. Experiments made at Dalkeith in 1877 by Mr. Lavington E. Fletcher. (The Engineer, 24 August 1877.)

Jackets, *With* or *Without* Steam		Without	With
Duration of each of 2 trials	hours	7	6 & 7
Boiler Pressure, lbs. per square inch above atm.	lbs.	30 to 40	55 to 60
Number of Expansions		3·1	4·7
Revolutions per minute	revs.	52·5	53·2
Piston Speed, feet per minute	feet	367	372
Results. Indicated horse-power	I.H.P.	170	192
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·81
,, ,, in percentage of feed-water	p.c.	..	3·4
Feed-Water, lbs. per I.H.P. per hour	lbs.	28·51	24·10
,, percentage less with steam in jackets		..	**15·5 p.c.**

No. 21. *Record of two Experiments on same Engine*
WITH *and* WITHOUT *Steam in the Jackets.*

Single-Cylinder Condensing Pumping Engine of the Bède type with Corliss valves. *Cylinder* 39·37 inches diameter, 70·87 inches stroke; only the body of the cylinder was jacketed. Experiments made at Asnières in 1879 by MM. Farcot. Whole steam-supply to cylinders passed through the jacket when in use. (L'Ingénieur-Conseil, vol. 2, 1879.)

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	10	10
Boiler Pressure, lbs. per square inch above atm.	lbs.	59·6	61·8
Number of Expansions		13·4	15
Revolutions per minute	revs.	26·8	27·7
Piston Speed, feet per minute	feet	317	327
Results. Indicated horse-power	I.H.P.	174	166
Feed-Water, lbs. per I.H.P. per hour	lbs.	22·38	18·55
,, percentage less with steam in jackets		..	**17·1 p.c.**

Single-Cylinder Condensing Engines (continued).

No. 22. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

SINGLE-CYLINDER CONDENSING BEAM PUMPING ENGINE. *Cylinder* 32 inches diameter, 66 inches stroke; only the body and bottom end were jacketed. Experiments made at Chatham Water Works, in July 1882, by Mr. John G. Mair. (Institution of Civil Engineers, vol. lxxix, 1884.)

Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of experiment	hours	6·5	6·5
Number of diagrams taken		26	26
Boiler Pressure, lbs. per square inch above atm.	lbs.	41·2	42
Number of Expansions		3·8	4·3
Revolutions per minute	revs.	20·3	20·3
Piston Speed, feet per minute	feet	223	223
Results. Indicated horse-power	I.H.P.	124	123
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	1·09
„ „ in percentage of feed-water	p.c.	..	4·9
Feed-Water, lbs. per I.H.P. per hour	lbs.	26·46	22·06
„ percentage less with steam in jackets		..	**16·6** p.c.

No. 23. *Record of forty-six Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

SINGLE-CYLINDER CONDENSING CORLISS ENGINE. *Cylinder* 21·65 inches diameter, 43·31 inches stroke; the body only was jacketed. Experiments made at the Creusot Works, France, in 1883, by M. Delafond. The jackets were supplied with steam by a small pipe from the main steam-pipe, and were automatically drained. (Annales des Mines, 1884, and L'Ingénieur-Conseil, 1885.)

Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of experiment	hours	1	1·2
Number of diagrams taken		24	28
Boiler Pressure, lbs. per square inch above atm.	lbs.	110	110
Number of Expansions		13·5	11·3
Revolutions per minute	revs.	60	58·8
Piston Speed, feet per minute	feet	433	424
Results. Indicated horse-power	I.H.P.	109	141
Feed-Water, lbs. per I.H.P. per hour	lbs.	23·24	17·05
„ percentage less with steam in jackets		..	**26·6** p.c.

(*Continued to page* 729.)

Single-Cylinder Condensing Engines (continued).

No. 23 (*continued from preceding page*).

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	1·75	0·9
Number of diagrams taken		42	22
Boiler Pressure, lbs. per square inch above atm.	lbs.	110	110
Number of Expansions		10·7	10
Revolutions per minute	revs.	58·6	61·5
Piston Speed, feet per minute	feet	423	444
Results. Indicated horse-power	I.H.P.	128·5	159·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	22·24	16·65
,, percentage less with steam in jackets		..	**25·1** p.c.
Duration of experiment	hours	1·25	1·3
Number of diagrams taken		30	32
Boiler Pressure, lbs. per square inch above atm.	lbs.	110	110
Number of Expansions		8·2	10
Revolutions per minute	revs.	59·4	59·9
Piston Speed, feet per minute	feet	429	432
Results. Indicated horse-power	I.H.P.	161	155
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·48
,, ,, in percentage of feed-water	p.c.	..	2·9
Feed-Water, lbs. per I.H.P. per hour	lbs.	21·41	16·50
,, percentage less with steam in jackets		..	**23·0** p.c.
Duration of experiment	hours	0·6	0·7
Number of diagrams taken		14	14
Boiler Pressure, lbs. per square inch above atm.	lbs.	110	110
Number of Expansions		6·4	6·4
Revolutions per minute	revs.	57·7	58·1
Piston Speed, feet per minute	feet	416	419
Results. Indicated horse-power	I.H.P.	186	212
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·56
,, ,, in percentage of feed-water	p.c.	..	3·2
Feed-Water, lbs. per I.H.P. per hour	lbs.	21·99	17·59
,, percentage less with steam in jackets		..	**20·0** p.c.
Duration of experiment	hours	2	1·6
Number of diagrams taken		48	36
Boiler Pressure, lbs. per square inch above atm.	lbs.	88·9	88·
Number of Expansions		9·3	12
Revolutions per minute	revs.	59·8	59·6
Piston Speed, feet per minute	feet	432	430
Results. Indicated horse-power	I.H.P.	126	112
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·53
,, ,, in percentage of feed-water	p.c.	..	3·0
Feed-Water, lbs. per I.H.P. per hour	lbs.	21·19	17·66
,, percentage less with steam in jackets		..	**16·7** p.c.

(*Continued on next page.*)

Single-Cylinder Condensing Engines (continued).

No. 23 (*continued from preceding page*).

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	1·7	1·7
Number of diagrams taken		40	40
Boiler Pressure, lbs. per square inch above atm.	lbs.	88·9	88·9
Number of Expansions		8·7	11·3
Revolutions per minute	revs.	59·3	59·6
Piston Speed, feet per minute	feet	428	430
Results. Indicated horse-power	I.H.P.	134	124
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·54
" " in percentage of feed-water	p.c.	..	3·1
Feed-Water, lbs. per I.H.P. per hour	lbs.	21·05	17·32
" percentage less with steam in jackets		..	**17·7 p.c.**
Duration of experiment	hours	1·5	0·7
Number of diagrams taken		36	16
Boiler Pressure, lbs. per square inch above atm.	lbs.	88·9	88·9
Number of Expansions		7·3	6·8
Revolutions per minute	revs.	59·8	59·4
Piston Speed, feet per minute	feet	432	429
Results. Indicated horse-power	I.H.P.	150	176
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·2
" " in percentage of feed-water	p.c.	..	1·2
Feed-Water, lbs. per I.H.P. per hour	lbs.	20·79	16·87
" percentage less with steam in jackets		..	**18·8 p.c.**
Duration of experiment	hours	0·9	0·7
Number of diagrams taken		22	16
Boiler Pressure, lbs. per square inch above atm.	lbs.	88·9	88·9
Number of Expansions		5·9	5·9
Revolutions per minute	revs.	58	60
Piston Speed, feet per minute	feet	419	433
Results. Indicated horse-power	I.H.P.	175	193
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·26
" " in percentage of feed-water	p.c.	..	1·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	19·89	17·50
" percentage less with steam in jackets		..	**12·0 p.c.**
Duration of experiment	hours	0·8	0·7
Number of diagrams taken		20	16
Boiler Pressure, lbs. per square inch above atm.	lbs.	88·9	88·9
Number of Expansions		4·8	5·9
Revolutions per minute	revs.	59·1	60
Piston Speed, feet per minute	feet	427	433
Results. Indicated horse-power	I.H.P.	194	193
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·26
" " in percentage of feed-water	p.c.	..	1·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	20·43	17·50
" percentage less with steam in jackets		..	**14·3 p.c.**

(*Continued on next page.*)

Single-Cylinder Condensing Engines (continued).

No. 23 (*continued from preceding page*).

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	1·5	1·9]
Number of diagrams taken		36	46
Boiler Pressure, lbs. per square inch above atm.	lbs.	64	64
Number of Expansions		10·8	10·7
Revolutions per minute	revs.	58·3	59·9
Piston Speed, feet per minute	feet	421	432
Results. Indicated horse-power	I.H.P.	85·3	91·7
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·46
,, ,, in percentage of feed-water	p.c.	..	2·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	20·41	18·48
,, percentage less with steam in jackets		..	**9·4** p.c.
Duration of experiment	hours	1·5	1·5
Number of diagrams taken		36	36
Boiler Pressure, lbs. per square inch above atm.	lbs.	64	64
Number of Expansions		8·2	8·2
Revolutions per minute	revs.	59·5	59·6
Piston Speed, feet per minute	feet	429	430
Results. Indicated horse-power	I.H.P.	115	117
Feed-Water, lbs. per I.H.P. per hour	lbs.	19·09	17·59
,, percentage less with steam in jackets		..	**7·8** p.c.
Duration of experiment	hours	1·25	1·5
Number of diagrams taken		30	36
Boiler Pressure, lbs. per square inch above atm.	lbs.	64	64
Number of Expansions		5·4	5·4
Revolutions per minute	revs.	59	58·8
Piston Speed, feet per minute	feet	426	424
Results. Indicated horse-power	I.H.P.	150	150
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·31
,, ,, in percentage of feed-water	p.c.	..	1·8
Feed-Water, lbs. per I.H.P. per hour	lbs.	18·06	17·34
,, percentage less with steam in jackets		..	**4·0** p.c.
Duration of experiment	hours	1·25	1·2
Number of diagrams taken		30	28
Boiler Pressure, lbs. per square inch above atm.	lbs.	64	64
Number of Expansions		3·9	4·4
Revolutions per minute	revs.	58·3	59·1
Piston Speed, feed per minute	feet	421	427
Results. Indicated horse-power	I.H.P.	172	175
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·26
,, ,, in percentage of feed-water	p.c.	..	1·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	18·37	17·66
,, percentage less with steam in jackets		..	**3·9** p.c.

(*Continued on next page.*)

Single-Cylinder Condensing Engines (continued).

No. 23 (*continued from preceding page*).

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	0·5	0·8
Number of diagrams taken		12	20
Boiler Pressure, lbs. per square inch above atm.	lbs.	64	64
Number of Expansions		3·6	3·6
Revolutions per minute	revs.	59·2	59
Piston Speed, feet per minute	feet	427	426
Results. Indicated horse-power	I.H.P.	186	194
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·3
„ „ in percentage of feed-water	p.c.	..	1·6
Feed-Water, lbs. per I.H.P. per hour	lbs.	18·84	18·55
„ percentage less with steam in jackets		..	1·5 p.c.
Duration of experiment	hours	1·2	1·6
Number of diagrams taken		28	38
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		10·7	12
Revolutions per minute	revs.	60·7	60·3
Piston Speed, feet per minute	feet	438	435
Results. Indicated horse-power	I.H.P.	75·6	68·8
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·5
„ „ in percentage of feed-water	p.c.	..	2·6
Feed-Water, lbs. per I.H.P. per hour	lbs.	20·65	19·29
„ percentage less with steam in jackets		..	6·6 p.c.
Duration of experiment	hours	1·3	1·1
Number of diagrams taken		32	24
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		7·9	7·6
Revolutions per minute	revs.	58·8	57·6
Piston Speed, feet per minute	feet	424	416
Results. Indicated horse-power	I.H.P.	94·3	95·5
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·43
„ „ in percentage of feed-water	p.c.	..	2·3
Feed-Water, lbs. per I.H.P. per hour	lbs.	19·36	18·48
„ percentage less with steam in jackets.		..	4·5 p.c.
Duration of experiment	hours	1·9	1
Number of diagrams taken		44	24
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		5·6	5·8
Revolutions per minute	revs.	60·4	59·7
Piston Speed, feet per minute	feet	436	431
Results. Indicated horse-power	I.H.P.	120	120
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·25
„ „ in percentage of feed-water	p.c.	..	1·4
Feed-Water, lbs. per I.H.P. per hour	lbs.	18·77	18·17
„ percentage less with steam in jackets		..	3·2 p.c.

(*Continued on next page.*)

Single-Cylinder Condensing Engines (continued).

No. 23 (*continued from preceding page*).

Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of experiment	hours	0·9	1·2
Number of diagrams taken		20	28
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		4·2	4
Revolutions per minute	revs.	58·8	60·1
Piston Speed, feet per minute	feet	424	434
Results. Indicated horse-power	I.H.P.	140	152
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·26
,, ,, in percentage of feed-water	p.c.	..	1·4
Feed-Water, lbs. per I.H.P. per hour	lbs.	19·0	18·91
,, percentage less with steam in jackets		..	**0·47 p.c.**
Duration of experiment	hours	0·9	0·8
Number of diagrams taken		22	20
Boiler Pressure, lbs. per square inch above atm.	lbs.	49·8	49·8
Number of Expansions		3·2	3·2
Revolutions per minute	revs.	59·4	59·5
Piston Speed, feet per minute	feet	429	430
Results. Indicated horse-power	I.H.P.	165	179
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·24
,, ,, in percentage of feed-water	p.c.	..	1·2
Feed-Water, lbs. per I.H.P. per hour	lbs.	19·78	19·67
,, percentage less with steam in jackets		..	**0·56 p.c.**
Duration of experiment	hours	1·4	1·2
Number of diagrams taken		34	28
Boiler Pressure, lbs. per square inch above atm.	lbs.	35·6	35·6
Number of Expansions		4·7	4·6
Revolutions per minute	revs.	60·3	60·7
Piston Speed, feet per minute	feet	435	438
Results. Indicated horse-power	I.H.P.	106	111
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·32
,, ,, in percentage of feed-water	p.c.	..	1·6
Feed-Water, lbs. per I.H.P. per hour	lbs.	20·45	19·78
,, percentage less with steam in jackets		..	**3·3 p.c.**
Duration of experiment	hours	1·1	1·3
Number of diagrams taken		26	32
Boiler Pressure, lbs. per square inch above atm.	lbs.	35·6	35·6
Number of Expansions		2·2	2·3
Revolutions per minute	revs.	61·1	61·9
Piston Speed, feet per minute	feet	441	447
Results. Indicated horse-power	I.H.P.	160	162
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·24
,, ,, in percentage of feed-water	p.c.	..	1·1
Feed-Water, lbs. per I.H.P. per hour	lbs.	22·73	22·08
,, percentage less with steam in jackets		..	**2·9 p.c.**

(*Concluded on next page.*)

Single-Cylinder Condensing Engines (concluded).

No. 23 (*concluded from page* 723).

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	0·7	0·7
Number of diagrams taken		16	16
Boiler Pressure, lbs. per square inch above atm.	lbs.	35·6	35·6
Number of Expansions		1·7	1·7
Revolutions per minute	revs.	61	61·1
Piston Speed, feet per minute	feet	440	441
Results. Indicated horse-power	I.H.P.	181	180
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·15
„ „ in percentage of feed-water	p.c.	..	0·6
Feed-Water, lbs. per I.H.P. per hour	lbs.	25·26	25·41
„ p.c. less *without* steam in jackets		0·61 p.c.	..
Duration of experiment	hours	0·3	0·4
Number of diagrams taken		8	10
Boiler Pressure, lbs. per square inch above atm.	lbs.	35·6	35·6
Number of Expansions		1	1
Revolutions per minute	revs.	60	60·4
Piston Speed, feet per minute	feet	433	436
Results. Indicated horse-power	I.H.P.	182	199
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	0·66
„ „ in percentage of feed-water	p.c.	..	0·2
Feed-Water, lbs. per I.H.P. per hour	lbs.	35·87	33·01
„ percentage less with steam in jackets		..	8·0 p.c.

See also set of Experiments No. 8.

End of Experiments on Single-Cylinder Condensing Engines.

For Experiments on Compound Condensing Engines see next page.

COMPOUND CONDENSING ENGINES.

No. 24. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Beam Engine. *Cylinders,* $13\frac{3}{8}$ and $29\frac{13}{32}$ inches diameter, $49\frac{5}{8}$ and $66\frac{3}{4}$ inches stroke; only the body and bottom end of each were jacketed. Experiments made at Messrs. Haussmann's Cotton Mill at Logelbach, near Colmar in 1854 and 1855 by Mr. G. A. Hirn, who also records an experiment made on another engine by jacketing the cylinder with smoke, the effect of which was found to be almost nil. (Société Industrielle de Mulhouse, vol. xxvii, 1855.)

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	12	12
Boiler Pressure, lbs. per square inch above atm.	lbs.	55·8	55·8
Number of Expansions		4·3	4·3
Revolutions per minute	revs.	23·5	23·5
Piston Speeds, feet per minute	feet	194 & 261	194 & 261
Results. Jacket-Water lbs. per *Brake* H.P. per hour	lbs.	..	0·92
„ „ in percentage of feed-water	p c.	..	5·2
Brake Horse-Power	B.H.P.	78·4	102·6
„ percentage more with steam in jackets		..	**23·5** p.c.

No. 25. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Beam Engine. 8 H.P. *Cylinders* $7\frac{5}{16}$ inches and 14 inches diameter, $26\frac{1}{8}$ and 36 inches stroke; only the body and bottom end of each were jacketed. Experiments made at Bermondsey in March 1859 by Messrs. Farey and B. Donkin, Jun. The whole steam-supply to the cylinders passed through the jackets when in use.

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	4	4
Number of top-diagrams taken		18	20
Boiler Pressure, lbs. per square inch above atm.	lbs.	41	41
Number of Expansions		5·5	5·5
Revolutions per minute	revs.	36·7	36·3
Piston Speeds, feet per minute	feet	160 & 220	158 & 218
Results. Indicated horse-power	I.H.P.	16·7	19·8
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	2·84
„ „ in percentage of feed-water	p.c.	..	8·9
Feed-Water, lbs. per I.H.P. per hour	lbs.	44·48	31·74
„ percentage less with steam in jackets		..	**28·6** p.c.

Compound Condensing Engines (continued).

No. 26. *Record of three Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Beam Engine. *Cylinders* $13\frac{3}{16}$ and 24 inches diameter, $39\frac{3}{8}$ and 54 inches stroke; only the body and bottom end of each were jacketed. Experiments made at Bermondsey in 1868 by Messrs. Farey and B. Donkin, Jun. Whole steam-supply to cylinders passed through the jackets when in use, except in last column when steam at only 4 lbs. pressure was admitted to the jackets.

Jackets, *With* or *Without* Steam		Without	With	Pressure 4 lbs. only.
Duration of experiment	hours	10	10	5
Number of diagrams taken		88	84	—
Boiler Pressure, lbs. per sq. in. above atm.	lbs.	41·1	40·9	41
Number of Expansions		14	11	12
Revolutions per minute	revs.	32·0	32·5	32·6
Piston Speeds, feet per minute	feet	210 & 288	213 & 292	214 & 294
Results. Indicated horse-power	I.H.P.	27·8	46·2	37·2
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	3·86	2·81
,, ,, in p.c. of feed-water	p.c.	..	17·1	9·9
Feed-Water, lbs. per I.H.P. per hour	lbs.	32·74	22·51	28·27
,, p.c. less with steam in jackets		..	**31·2 p.c.**	**13·7 p.c.**

No. 27. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Beam Engine. *Cylinders* $7\frac{5}{16}$ and 14 inches diameter, $26\frac{1}{8}$ and 36 inches stroke; only the body and bottom end of each were jacketed. Experiments made at Bermondsey in 1870 by Messrs. Farey and B. Donkin, Jun. Whole steam-supply to cylinders passed through the jackets when in use.

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	3	3
Number of diagrams taken		48	48
Boiler Pressure, lbs. per square inch above atm.	lbs.	45	45
Number of Expansions		10·3	10·3
Revolutions per minute	revs.	37·4	43·7
Piston Speeds, feet per minute	feet	163 & 224	190 & 262
Results. Indicated horse-power	I.H.P.	9·7	16·5
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	5·67
,, ,, in percentage of feed-water	p.c.	..	23·4
Feed-Water, lbs. per I.H.P. per hour	lbs.	39·49	24·25
,, percentage less with steam in jackets		..	**38·6 p.c.**

Compound Condensing Engines (continued).

No. 28. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Beam Engine. *Cylinders* $20\frac{3}{16}$ and $31\frac{1}{4}$ inches diameter, $51\frac{5}{8}$ and $70\frac{7}{8}$ inches stroke; only the low-pressure cylinder and intermediate passage were jacketed, the latter always. Experiments made at Maestricht, Belgium, in March 1873 by M. Lhoest. (Revue Universelle des Mines, 1873.) The author did not consider the experiments altogether satisfactory, as the steam could not be entirely shut off from the jacket, owing to the peculiar construction of the engine.

Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of experiment	hours	12	12
Boiler Pressure, lbs. per square inch above atm.	lbs.	60	60
Number of Expansions		13	13
Revolutions per minute	revs.	25	25
Piston Speeds, feet per minute	feet	215 & 295	215 & 295
Results. Indicated horse-power	I.H.P.	119	119
Feed-Water, percentage less with steam in jackets		..	**4 to 5** p.c.

No. 29. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Marine Engine. *Cylinders* 16 and 25 inches diameter, 24 inches stroke. Experiments made on s.s. "Bache" at Baltimore, U.S.A., in 1874, by Mr. C. E. Emery. (American Official Reports.)

Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of experiment	hours	2·1	1·9
Boiler Pressure, lbs. per square inch above atm.	lbs.	80·3	80·2
Number of Expansions		6·7	7
Revolutions per minute	revs.	47·7	53·2
Piston Speed, feet per minute	feet	191	213
Results. Indicated horse-power	I.H.P.	77·1	99·2
Feed-Water, lbs. per I.H.P. per hour	lbs.	23·04	20·33
„ percentage less with steam in jackets		..	**11·7** p.c.

See also set of Experiments No. 17.

Compound Condensing Engines (continued).

No. 30. *Record of twenty-two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Horizontal Tandem Experimental Engine. *Cylinders* 6 inches and 10 inches diameter, 12 inches stroke; only the bodies of the cylinders were jacketed. Experiments made at Bermondsey from 1875 to 1881 by Messrs. Farey, B. Donkin, Jun., and Salter. The whole steam-supply to the cylinders passed through the jackets, when in use, which were drained by traps. When not in use the jackets were open to the air.

For each of the twenty-two experiments:—

Duration of experiment	0·5 hour.
Number of diagrams taken	16
Boiler Pressure, lbs. per square inch above atm. .	42 lbs.
Revolutions per minute	98 revs.
Piston Speed, feet per minute	196 feet.

Four Experiments WITHOUT Steam in Either Jacket.

Both Jackets, *Without* Steam		**Without**	**Without**
Number of Expansions		8·38	7·54
Results. Indicated horse-power	I.H.P.	7·10	8·04
Thermal units rejected per I.H.P. per minute	Th.U.	525	533
Number of Expansions		5·80	4·45
Results. Indicated horse-power	I.H.P.	9·37	10·51
Thermal units rejected per I.H.P. per minute	Th.U.	619	574

Three Experiments WITH Steam in High-Pressure Jacket alone.

High-Pressure Jacket alone, *With* Steam		**With**	**With**	**With**
Number of Expansions		10·78	7·73	7·01
Results. Indicated horse-power	I.H.P.	6·72	8·03	8·84
Jacket-Water, lbs. per I.H.P. per hour	lbs.	4·2	3·9	3·24
Thermal units rejected per I.H.P. per minute	Th.U.	420	420	418

(*Continued to page* 735.)

Compound Condensing Engines (continued).

No. 30 (*continued from preceding page*).

AVERAGE RESULTS FROM THE FOREGOING THREE EXPERIMENTS WITH STEAM IN HIGH-PRESSURE JACKET ALONE, AND FOUR EXPERIMENTS WITHOUT STEAM IN EITHER JACKET.

High-Pressure Jacket alone, *With* or *Without* Steam		Without	With
Results. Indicated horse-power	I.H.P.	8·75	7·86
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	3·78
Thermal units rejected per I.H.P per minute	Th.U.	563	419
„ „ percentage less with steam in jacket of High-Pressure Cylinder alone		..	**25·5** p.c.

SEVEN EXPERIMENTS WITH STEAM IN LOW-PRESSURE JACKET ALONE.

Low-Pressure Jacket alone, *With* Steam		With	With	With
Number of Expansions		15·8	9·74	9·14
Results. Indicated horse-power	I.H.P.	6·88	8·72	9·02
Jacket-Water, lbs. per I.H.P. per hour	lbs.	5·76	4·8	4·14
Thermal units rejected per I.H.P. per minute	Th.U.	427	380	388
Number of Expansions		8·38	7·54	
Results. Indicated horse-power	I.H.P.	9·82	10·94	
Jacket-Water, lbs. per I.H.P. per hour	lbs.	3·9	3·78	
Thermal units rejected per I.H.P. per minute	Th.U.	383	385	
Number of Expansions		7·18	5·38	
Results. Indicated horse-power	I.H.P.	11·44	12·39	
Jacket-Water, lbs. per I.H.P. per hour	lbs.	4·02	3·24	
Thermal units rejected per I.H.P. per minute	Th.U.	407	427	

AVERAGE RESULTS FROM THE FOREGOING SEVEN EXPERIMENTS WITH STEAM IN LOW-PRESSURE JACKET ALONE, AND FOUR EXPERIMENTS WITHOUT STEAM IN EITHER JACKET.

Low-Pressure Jacket alone, *With* or *Without* Steam		Without	With
Results. Indicated horse-power	I.H.P.	8·75	9·89
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	4·26
Thermal units rejected per I.H.P. per minute	Th.U.	563	400
„ „ percentage less with steam in jacket of Low-Pressure Cylinder alone		..	**29** p.c.

(*Concluded on next page.*)

Compound Condensing Engines (continued).

No. 30 (*concluded from page* 733).

EIGHT EXPERIMENTS WITH STEAM IN BOTH JACKETS.

Both Jackets, *With* Steam	**With**	**With**	**With**
Number of Expansions	13·1	13·1	8·38
Results. Indicated horse-power I.H.P.	6·50	7·01	8·85
Jacket-Water, lbs. per I.H.P. per hour lbs.	6·6	6·6	4·8
Thermal units rejected per I.H.P. per minute Th.U.	347	348	375
Number of Expansions	9·14	7·54	6·70
Results. Indicated horse-power I.H.P.	9·05	9·08	10·53
Jacket-Water, lbs. per I.H.P. per hour lbs.	5·4	6·6	5·4
Thermal units rejected per I.H.P. per minute Th.U.	367	372	385

Number of Expansions	5·80	4·64
Results. Indicated horse-power I.H.P.	11·82	12·87
Jacket-Water, lbs. per I.H.P. per hour lbs.	4·2	4·8
Thermal units rejected per I.H.P. per minute Th.U.	370	410

AVERAGE RESULTS FROM THE FOREGOING EIGHT EXPERIMENTS WITH STEAM IN BOTH JACKETS, AND FOUR EXPERIMENTS WITHOUT STEAM IN EITHER JACKET.

Both Jackets, *With* or *Without* Steam	**Without**	**With**
Results. Indicated horse-power I.H.P.	8·75	9·46
Jacket-Water, lbs. per I.H.P. per hour lbs.	..	5·55
Thermal units rejected per I.H.P. per minute Th.U.	563	372
„ „ percentage less with steam in both jackets	..	**33·9** p.c.

Compound Condensing Engines (continued).

No. 31. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Woolf Beam Pumping Engine. *Cylinders* 22 and 34 inches diameter, 43 and 66 inches stroke; the body and both ends of each cylinder were jacketed. Experiments made at Chatham Water Works in August 1881 by Mr. John G. Mair. (Institution of Civil Engineers, vol. lxx, 1882.)

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	6	10
Number of diagrams taken		52	124
Boiler Pressure, lbs. per sq. in. above atm.	lbs.	43·3	47·3
Number of Expansions		9·3	15·8
Revolutions per minute	revs.	17·8	19·6
Piston Speeds, feet per minute	feet	128 & 196	141 & 216
Results. Indicated horse-power	I.H.P.	75·9	75·2
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	1·72
,, ,, in percentage of feed-water	p.c.	..	9·9
Feed-Water, lbs. per I.H.P. per hour	lbs.	26·62	17·34
,, p.c. less with steam in jackets		..	**34·9 p.c.**

No. 32. *Record of two Experiments on same Engine* WITH *and* WITHOUT *Steam in the Jackets.*

Compound Condensing Woolf Beam Engine driving a flour mill. *Cylinders* 24½ and 38 inches diameter, 41 and 66 inches stroke; only the body of each was jacketed. Experiments made in London in December 1881 by Mr. John G. Mair. (Institution of Civil Engineers, vol. lxx, 1882.)

Jackets, *With* or *Without* Steam		Without	With
Duration of experiment	hours	10	21
Number of diagrams taken		124	264
Boiler Pressure, lbs. per sq. in. above atm.	lbs.	74·3	71·8
Number of Expansions		7·8	9·6
Revolutions per minute	revs.	34·5	34
Piston Speeds, feet per minute	feet	236 & 380	232 & 374
Results. Indicated horse-power	I.H.P.	268	268
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	1·35
,, ,, in percentage of feed-water	p.c.	..	7·7
Feed-Water, lbs. per I.H.P. per hour	lbs.	19·24	17·56
,, p.c. less with steam in jackets		..	**8·7 p.c.**

Compound Condensing Engines (continued).

No. 33. *Record of two Experiments on same Engine*

WITH *and* WITHOUT *Steam in the Jackets.*

Compound Surface-Condensing Three - Cylinder Vertical Inverted Engine. *Cylinders* 19, 25, and 25 inches diameter, 24 inches stroke; only the bodies of the cylinders were jacketed. Experiments made at the London Hydraulic Power Pumping Station in 1887 by Professor Kennedy and Mr. B. Donkin, Jun. Steam-supply to jackets by small pipe. Steam from small cylinder expanded into two large cylinders.

Jackets, *With* or *Without* Steam		**Without**	**With**
Duration of experiment	hours	9	9
Boiler Pressure, lbs. per square inch above atm.	lbs.	80	80
Number of Expansions		7	7
Revolutions per minute	revs.	55	55
Piston Speed, feet per minute	feet	220	220
Results. Indicated horse-power	I.H.P.	157	168
Jacket-Water, lbs. per I.H.P. per hour	lbs.	..	1·32
" " in percentage of feed-water	p.c.	..	6·5
Feed-Water, lbs. per I.H.P. per hour	lbs.	23·93	20·25
" percentage less with steam in jackets		..	**15·4** p.c.

Compound Condensing Engines (continued).

No. 34.

EXPERIMENTS ON THE COMPARATIVE EFFICIENCY OF A COMPOUND CONDENSING ENGINE WORKING WITH AND WITHOUT STEAM IN JACKETS.

By PROFESSOR ALEXANDER B. W. KENNEDY, F.R.S.,
Honorary Life Member.

Engine.—The experimental engine at University College, London, with which the trials recorded in Table 34 were carried out, is of the compound tandem type manufactured by Messrs. Bryan Donkin and Co., and has already been fully described and illustrated in "Engineering," vol. xvii, p. 303; vol. xxi, p. 203; and vol. xxxiv, p. 603. It is the same engine with which the previous experiments No. 30 were made.

The cylinders are 6 inches and 10 inches in diameter. An expansion valve of the Meyer type is fitted to the high-pressure cylinder, by means of which the cut-off can be made to take place at any point in the stroke. The ports are disposed unsymmetrically about the centre line of the cylinders in such a manner as to prevent any serious accumulation of water. Both cylinders are jacketed, and during the trials the steam circulated through both jackets before entering the high-pressure valve-chest. When the jackets were not in use, the traps were left wide open in order to allow any steam that might leak through into the jackets to escape at once.

Boiler.—The boiler used before No. 80 of these trials was of the vertical multitubular type, but it was judged that it made very wet steam. A new boiler, of the locomotive type, manufactured by Messrs. Lindsay Burnet and Co., was therefore substituted. A separator is fixed on the steam pipe near the boiler; and as the boiler is very much under-worked, very dry steam is supplied.

Explanation of Table.—In the selection of the trials, from the results of which the Table 34 has been compiled, preference was given to those whose duration was not less than two hours; but unavoidably some trials have been used which did not last so long, whilst others extended over five and seven hours. As far as possible the trials have been tabulated in pairs of one jacketed and one non-jacketed carried out under as nearly as practicable the same conditions.

Lines *a*, *b*, *h*, *m*, *y*, and *z* need no comment.

Line *c* is the real ratio of expansion, that is, the ratio of the low-pressure piston displacement plus the clearance, to the volume at cut-off in the high-pressure cylinder plus the clearance.

Lines *d* and *e* show the mean net weight of steam in the high-pressure cylinder at cut-off, allowance being made for the dead clearance steam, in pounds per minute. The values in line *d* are calculated for a uniform speed of 100 revolutions per minute, the values in line *e* being calculated for the actual mean speed observed during the trial. The quantities in this line are the mean values calculated from all the diagrams taken from both ends of the cylinder.

Line *f* gives the net weight of steam and water passing through the cylinders in pounds per minute. These values are obtained by subtracting the whole trap-water (which includes water condensed in the jackets as well as in the steam pipe, and any leakage) from the total feed which is measured directly.

Line *g* is the difference between lines *f* and *e*, the mean amount of water contained in the mixed steam and water in the high-pressure cylinder at cut-off.

Line *i* shows the indicated horse-power. Diagrams were taken by four indicators simultaneously, one on each end of each cylinder. In the two-hour trials diagrams were taken every fifteen minutes; in the seven-hour trials every thirty minutes.

Line *j* gives the quantities in line *f* expressed in pounds per I.H.P. per hour.

Line *k* shows the weighed amount of water drawn from the feed tank by the feed pump, minus or plus any difference in the boiler at

the end of the trial, expressed in pounds per I.H.P. per hour. The difference between lines j and k is represented by and equal to the sum of lines m, n, o, and r.

Line l gives the saving of feed-water per indicated horse-power, and compares with the corresponding final percentages in the preceding tables.

Lines n and o.—In the earlier trials the condensed steam from the steam pipe was discharged through the low-pressure trap, while in the more recent trials a separate trap was fixed to the steam pipe.

Line p shows the amount of water due to condensation caused by the action of the cylinder walls. These values were arrived at in the following way. After each trial the engine was left standing with full steam in the jackets for two hours. The water issuing from the traps was weighed and assumed to be equal to that due to radiation when the engine was running.

This amount, which is that given in line q, is subtracted from the total trap-water measured during the trial, and the difference is credited to condensation due to transmission of heat through the cylinder walls. The amount of steam condensed in the steam pipe was somewhat greater when the engine was running than when it was standing. The difference, which was very small, was allowed for.

Lines p and q together show the same quantity of water as lines m, n, and o, but differently subdivided.

Line r gives the amount of water that issued from the separator. In the cases of trials Nos. 103 and 105 this also includes some small leakage in the engine and in some of the boiler mountings.

Line s gives the value of the steam that passed through the cylinder per I.H.P. per hour, calculated from the discharge over the tumbling bay. In the more recent trials the injection water was separately measured before going to the condenser. This makes it possible to ascertain separately, by calculation, the amount of steam and water which leaves the engine. The values given in line s are approximately equal to those of line j minus this calculated amount of water which is given separately in line v; the reason for the equality being only approximate in the earlier experiments is the method then adopted for obtaining the values in line v, as explained under v in the next page.

Line t gives the ratio of the amount of net feed (that is, the whole weight of the mixture) in line f, to the weight of steam alone at cut-off in the high-pressure cylinder, in line e. If unity be subtracted from the figures in line t, the difference is the ratio of water to steam at cut-off in the high-pressure cylinder. The reciprocal of the figures in line t is the ratio of the weight of steam to the whole weight of the mixture.

Line u gives the difference between the weight of the mixed steam and water passing through the engine in line j, and that of the steam alone found at the end of the low-pressure stroke in line s; that is, it gives the amount of water at the end of the stroke in the low-pressure cylinder. The figures given in this line ought therefore to be equal to those of line v, which, as already stated, gives the calculated amount of water. In the recent trials, where the injection water was directly measurable, these two lines are really identical. But in the older trials—where the only means of getting at the amount of condensing water per minute was by calculating the number of pounds of condensing water per pound of steam, from the heat contained in each pound of steam condensed and the rise of temperature in the condenser, and then deducing the amount of condensing water and of condensed steam per minute from the total discharge over the tumbling bay per minute—an error was naturally involved, which causes the discrepancy already referred to between the values found in these two lines.

Line w gives the net weight of steam and water passing to the engine, which is the total feed minus all sources of loss other than that portion p of the trap-water which is determined to be due to the quantity of jacket steam condensed in consequence of transference of heat through the cylinder walls. These values w are equal to the sums of corresponding values in lines j and p.

Line x contains the discrepancy between the total quantity of heat received and the sum of the different quantities of heat rejected plus the thermal equivalent of the work done, the difference being expressed as a percentage of the total heat received. It is in fact the balance unaccounted for in the "Heat Account," which was worked out in full for every trial, although the details are not given here.

Compound Condensing Engines (continued).

TABLE 34 (*continued to page* 745).

Comparative results of Compound Condensing Steam-Engine Trials

WITH *and* WITHOUT *Steam in Jackets.*

	Trial Number.		100	83; 102	*a*
	N Jackets Not in use; J both Jackets in use;		N	J	
	Absolute Boiler Pressure in lbs. per square inch	lbs.	39·4	48·3	*b*
	Ratio of Expansion (actual)		3·23	3·56	*c*
	Steam per min. in High-p. cylinder at cut-from diagrams, 100 revs. per min.	lbs.	2·59	3·14	*d*
	Steam per min. in High-p. cylinder at cut-off, from diagrams, actual speed	bs.	2·49	3·02	*e*
	Steam and water through cyl. per min., measured	lbs.	4·83	4·52	*f*
	Steam condensed in High-p. cylinder up to cut-off per minute	lbs.	2·34	1·50	*g*
	Revolutions per minute	revs.	96·1	96·2	*h*
	Indicated horse-power	I.H.P.	7·25	9·74	*i*
	Steam and water thro. cyl. per I.H.P. per hour	lbs.	40·00	27·85	*j*
	Feed-water per I.H.P. per hour, total	lbs.	41·60	31·75	*k*
	„ percentage less with steam in jackets		—	**23·7 p.c.**	*l*
Trap-Water, lbs. per I.H.P. per hour.	High-pressure Jacket	lbs.	—	1·05	*m*
	Low „ „	lbs.	—	2·47	*n*
	Steam Pipe	lbs.	0·96		*o*
	Credited to Cylinder walls	lbs.	—	1·67	*p*
	Radiation and Condensation in pipes	lbs.	0·96	1·85	*q*
	Priming Water from separator	lbs.	0·69	—	*r*
	Steam through cylinder per I.H.P. per hour, calculated from discharge	lbs.	33·99	25·38	*s*
	Ratio of steam and water to steam in High-p. cylinder at cut-off		1·94	1·50	*t*
	Water in Low-p. cylinder at end of stroke	lbs.	6·01	2·47	*u*
	„ „ „ „ calculated	lbs.	6·01	2·74	*v*
	Net steam and water to engine per I.H.P. per hour	lbs.	40·00	29·50	*w*
	Percentage of Heat not accounted for	p.c.	1·29	4·55	*x*
	Ratio of total trap-water to feed-water		0·039	0·124	*y*
	Duration of trial	hours	2	2; 2	*z*

Compound Condensing Engines (continued).

(*continued on next page*) TABLE 34.

Comparative results of Compound Condensing Steam-Engine Trials

WITH *and* WITHOUT *Steam in Jackets.*

a	98	54	18	38	17	44	16	19
	N	J	N	J	N	J	N	J
b	59·6	57·8	77·4	78·0	76·5	87·8	80·0	82·1
c	3·15	4·53	8·72	8·87	5·92	5·72	8·95	11·10
d	4·12	2·65	1·79	1·83	2·78	2·63	1·90	1·42
e	4·00	2·68	1·78	1·79	2·70	2·61	1·43	1·41
f	6·35	3·91	4·68	3·88	5·92	5·11	4·63	3·32
g	2·35	1·23	2·90	2·09	3·22	2·50	3·20	1·91
h	97·0	101·0	99·1	98·25	97·35	99·3	75·3	99·0
i	10·44	9·33	8·77	9·23	9·57	11·81	6·90	8·45
j	36·48	25·14	32·03	25·21	37·16	25·94	40·33	23·62
k	37·07	28·04	33·27	28·66	38·62	29·38	42·98	27·86
l	—	**24·4** p.c.	—	**13·9** p.c.	—	**23·9** p.c.	—	**35·2** p.c.
m	—	1·41	—	1·41	—	1·22	—	1·44
n	—	1·49	—	2·04	—	2·22	—	2·80
o	0·59		1·24		1·46		2·65	
p	—	0·84	—	1·37	—	2·01	—	1·97
q	0·59	2·06	1·24	2·08	1·46	1·43	2·65	2·27
r	—	—	—	—	—	—	—	—
s	32·00	23·78	28·39	22·61	30·41	23·88	34·90	19·34
t	1·59	1·46	2·63	2·17	2·19	1·96	3·24	2·35
u	4·48	1·36	3·64	2·60	6·75	2·06	5·43	4·28
v	4·48	1·64	3·83	2·90	7·14	2·31	3·28	4·47
w	36·48	25·98	32·03	26·58	37·16	27·95	40·33	25·59
x	1·71	2·07	1·34	3·60	1·80	5·97	2·78	4·84
y	0·016	0·103	0·037	0·120	0·038	0·117	0·062	0·138
z	2	2	2	2	2	2	2	1·75

Compound Condensing Engines (continued).

TABLE 34 (*continued from preceding page*).

Comparative results of Compound Condensing Steam-Engine Trials

WITH *and* WITHOUT *Steam in Jackets.*

Trial Number.			73	75	*a*
N Jackets Not in use; J both Jackets in use;			N	J	
Absolute Boiler Pressure in lbs. per square inch		lbs.	87·7	85·0	*b*
Ratio of Expansion (actual)			3·00	3·60	*c*
Steam per min. in High-p. cylinder at cut-off, from diagrams, 100 revs. per min.		lbs.	4·18	3·64	*d*
Steam per min. in High-p. cylinder at cut-off, from diagrams, actual speed		lbs.	4·00	3·51	*e*
Steam and water through cyl. per min., measured		lbs.	6·67	5·80	*f*
Steam condensed in High-p. cylinder up to cut-off per minute		lbs.	2·67	2·29	*g*
Revolutions per minute		revs.	95·7	96·3	*h*
Indicated horse-power		I.H.P.	13·21	12·90	*i*
Steam and water thro. cyl. per I.H.P. per hour		lbs.	30·25	26·98	*j*
Feed-water per I.H.P. per hour, total		lbs.	30·90	29·53	*k*
" percentage less with steam in jackets			—	4·4 p.c.	*l*
Trap-Water, lbs. per I.H.P. per hour.	High-pressure Jacket	lbs.	—	2·55	*m*
	Low " "	lbs.	—		*n*
	Steam Pipe	lbs.	0·65		*o*
	Credited to Cylinder walls	lbs.	—	0·76	*p*
	Radiation and Condensation in pipes	lbs.	0·65	1·79	*q*
	Priming Water from separator	lbs.	—	—	*r*
Steam through cylinder per I.H.P. per hour, calculated from discharge		lbs.	27·84	24·46	*s*
Ratio of steam and water to steam in High-p. cylinder at cut-off			1·67	1·65	*t*
Water in Low-p. cylinder at end of stroke		lbs.	2·41	2·53	*u*
" " " " calculated		lbs.	2·65	2·78	*v*
Net steam and water to engine per I.H.P. per hour		lbs.	30·25	27·74	*w*
Percentage of Heat not accounted for		p.c.	1·03	2·06	*x*
Ratio of total trap-water to feed-water			0·021	0·086	*y*
Duration of trial		hours	1·5	5	*z*

Compound Condensing Engines (concluded).

(*concluded from page* 742) TABLE 34.

Comparative results of Compound Condensing Steam-Engine Trials

WITH *and* WITHOUT *Steam in Jackets.*

a	35	50	62	39	80	91	99	103; 105	105
	N	**J**	**N**	**J**	**N**	**J**	**N**	**J**	**J**
b	89·7	87·7	89·3	88·3	94·6	94·0	95·0	94·6	95·0
c	8·79	8·45	6·64	6·41	8·25	8·43	8·62	7·59	7·77
d	2·00	2·16	2·76	2·66	2·40	2·46	2·10	2·46	2·47
e	1·91	2·07	2·72	2·65	2·32	2·39	2·00	2·40	2·40
f	5·54	4·75	6·06	4·50	6·29	4·24	5·47	5·17	5·03
g	3·63	2·68	3·34	1·85	3·97	1·85	3·47	2·77	2·63
h	95·5	96·3	98·75	99·3	97·0	97·18	96·1	97·26	97·15
i	9·29	10·42	10·28	11·03	10·37	13·03	10·05	12·46	12·75
j	35·78	27·37	35·37	24·48	36·37	19·51	32·66	24·90	23 68
k	36·70	30·55	36·60	27·74	38·00	23·48	34·20	28·10	26·90
l	—	16·8 p.c.	—	24·2 p.c.	—	38·2 p.c.	—	17·8 p.c.	21·3 p.c.
m	—	1·36	—	1·24	—	1·34	—	0·64	0·52
n	—		—		—		—	1·02	0·97
o	0·92	1·82	1·23	2·02	1·63	1·84	1·03	0·50	0·50
p	—	1·34	—	1·52	—	1·18	—	0·91	0·76
q	0·92	1·84	1·23	1·74	1·63	2·00	1·03	1·25	1·24
r	—	—	—	—	—	0·77	0·49	1·03	1·23
s	28·80	22·92	29·77	23·50	30·08	19·78	28·64	20·18	21·28
t	2·90	2·30	2·23	1·70	2·71	1·77	2·74	2·15	2·10
u	6·88	4·45	5·60	0·74	6·29	0·49	4·02	4·21	1·58
v	6·98	4·89	5·91	0·84	6·57	0·12	4·02	4·21	1·58
w	35·68	28·71	35·37	25·76	36·37	20·70	32·66	25·81	24·44
x	1 60	4·20	1·82	4·30	1·97	2·19	2·13	1·60	2·4
y	0·025	0·104	0·034	0·117	0·043	0·168	0·045	0·076	0·074
z	2	5	2	2	1·8	2	2	7; 7·5	7·5

MEMOIRS.

Thomas Arthur Bewley, son of Mr. Thomas Bewley, J.P., of Rockville, County Dublin, was born there in 1844, and received his education first at a private school at Mountmellick, Queen's County, and afterwards at Grove House, Tottenham, London. Being fond of scientific pursuits, he attended a course of lectures at the Royal College of Science, Dublin, and there studied analytical chemistry, which he afterwards utilized at the large sugar refining establishment that his father was building at Ringsend, Dublin. From about the age of seventeen he worked for some years under his father at this business, until about 1869, when his father put him into the shipbuilding business of Messrs. Webb, Walpole, and Bewley, with his brother, Mr. John Bewley. Thenceforth he divided his time between the sugar refinery and the shipbuilding yard, until in 1878 his connection with the former ceased. In the shipbuilding yard he undertook the management of the engineering department. Being greatly devoted to the working of the optical lantern, and finding trouble and difficulty in preparing and storing gas, he was led to construct machinery for the purpose of compressing it at his works for his own use; succeeding in this, he made it after some time a branch of his business to supply cylinders of compressed gas. He gave lectures and entertainments in a thoroughly unselfish way to those who could only obtain such opportunities through the kindness and self-sacrifice of a man like himself. On the afternoon of 28th January 1889 he was preparing for a lantern entertainment, and was last seen walking up the stairs to his office with a cylinder of compressed gas under his arm. A few minutes afterwards a terrific explosion occurred, which partially wrecked the office buildings; and his body was found fearfully mutilated. It was subsequently proved that, through a series of unfortunate mistakes, the cylinder had been filled not with oxygen or hydrogen alone, but with a mixture of these

gases, forming a violently explosive compound; but it was impossible to ascertain with certainty what accident had caused their ignition, and had thus terminated his life at the age of forty-four. He was a member of the various scientific societies in Dublin, such as the Royal Dublin Society, Scientific and Microscopic Clubs, and the Photographic Society, to which he acted as treasurer. He became a Member of this Institution in 1882, and was also a member of the Society of Arts in London.

William Sutton Bocquet, son of Mr. Francis Bocquet of Liverpool, was born on 21st November 1848 at Fairfield near Liverpool, and was educated at the Liverpool College. In 1865 he went to India as assistant manager on a tea estate in Cachar; but owing to the malarious climate prevailing there he had to return to England in less than a year. On recovering health he went again to India at the end of 1867, and commenced his career on the Sind Punjab and Delhi Railway under his brother, Mr. Roscoe Bocquet, at that time locomotive superintendent of the line, and successively filled the posts of chief draughtsman, and assistant and district locomotive superintendent. On the amalgamation of that railway with the Indus Valley and Punjab Northern State lines in 1886, he was appointed by government as district locomotive superintendent; and at the time of his death he filled the responsible position of deputy locomotive superintendent on the North Western Railway. A great natural gift for mechanics, and untiring industry, coupled with an intimate acquaintance with the habits of the people and the conditions pertaining to Upper India, rendered him a most valuable officer. In addition to his official duties, he interested himself in the question of compressed fodder. In a country where distances are so enormous, and where from the nature of the climate supplies must mostly accompany an army, it is important that some simple means for reducing the bulk of hay and grass should be easily available; and he had devised a plan which gave every prospect of complete success, when his untimely death from dysentery took place at Lahore on 30th March 1889, at the age of forty. He became a Member of this Institution in 1881.

William Frederick Dennis was born at Hythe, in Kent, on 24th December 1844. After being educated at New Kingswood School, near Bath, he was articled to Messrs. Lloyds Fosters and Co., of Wednesbury, where he spent six years, passing through the various shops and departments. On leaving, he was employed in connection with the superintendence of the erection of Willesden Junction railway station; and subsequently, in order to gain a more diversified experience, he obtained employment with Messrs. R. and C. Goldthorpe, card-wire manufacturers, of Cleckheaton. In 1869 he went to London, and started an agency in the city, removing into larger premises as the business extended. He was afterwards joined in partnership by his brother, Mr. Arthur Dennis, and founded the firm of Messrs. W. F. Dennis and Co. As a business man he was one of the first to foresee the position which Germany was likely to attain as a commercial and manufacturing country and even when German productions were comparatively unknown in England he paid numerous visits to the manufacturing centres on the continent, and carried out large contracts with most successful results. As an engineer he invented the wire netting machine known by his name, by means of which wire netting is manufactured on a novel principle, direct from bobbins of hard bright steel wire, without the use of spools. He was also the inventor of a tubular telegraph pole, which is a combination of wrought and cast iron and is so constructed that it can be erected with great facility. He died at Eastbourne of heart disease on 10th December 1889, in the forty-fifth year of his age. He became a Member of this Institution in 1883.

Edward Fletcher was born on 26th April 1807, on the Cleugh Brae estate, in Reedwater, not far from Otterburn, Northumberland; and on the completion of his school education was apprenticed in 1825 to George Stephenson at his works in Newcastle. Just before leaving these works he made a considerable portion of the machinery of the Rocket locomotive, and was sent with the engine to the Killingworth wagon way. He was also with the Rocket when it made its famous run, prior to being sent to the

Liverpool and Manchester contest. Although he had not quite completed his apprenticeship, it was nearly settled that he should be sent to Carlisle to take charge of a saw-mill for cutting the sleepers for the Liverpool and Manchester line; but at the last moment, the proprietors of the Canterbury and Whitstable Railway being anxious to have that line opened, Mr. Stephenson sent him there. The line was opened and worked by the aid of two stationary engines and by horses. Shortly afterwards the horses were replaced by a locomotive, and the railway was gradually developed and extended. In 1837 he was actively engaged under Mr. Thomas Cabry in constructing the York and North Midland Railway, which was opened two years afterwards. In 1845 he became locomotive superintendent of the Newcastle and Darlington Railway; and when the High-Level Bridge at Newcastle was opened by the Queen in August 1859 he had charge of the royal train. In 1858 at the Newcastle meeting of this Institution he read a paper on the locomotive engine shed and turntables at Gateshead station. A prominent feature in his character was his ability to manage men, and his power of organisation was clearly exemplified during the great strike of engine-drivers and firemen on the North Eastern Railway in 1867. The presentation made to him by the directors for his services at that time, coupled with the address presented to him by the workmen in 1872, when they reviewed the various ways in which he had shown consideration for their interests, afford abundant proof of the esteem and confidence with which he was regarded by both employers and employed. In 1882 he retired, after forty-seven years spent in the service of the North Eastern Railway. He was a Member of this Institution from the commencement in 1847. His death occurred after a short illness at his residence, Osborne Avenue, West Jesmond, Newcastle-on-Tyne, on 21st December 1889, in the eighty-third year of his age.

James Simpson, the eldest son of the late Mr. James Simpson, Past-President of the Institution of Civil Engineers, was born on 10th January 1829 at Thames Bank, Chelsea, the residence of his father, who was at that time engineer to the Chelsea Water Works.

He was educated at St. Peter's Collegiate School, Eaton Square, and at Dr. Lord's private school at Tooting. In 1846 he was articled to Messrs. Burns and Bryce, architects, Edinburgh. Returning to London in 1851, he joined his father, who was at that time engaged in an extensive practice as a civil engineer, and superintended for him the erection of several important works, amongst others the construction of the water works at Carlisle, and the extension of the Chelsea Water Works to Surbiton, Surrey. In 1857 he joined the firm of Messrs. Simpson and Co., engineers, Pimlico, where he took a leading part in the introduction of improved pumping machinery, especially the Woolf compound pumping engines, and also in the construction of water works abroad. For the past few years failing health prevented his taking such an active part in the business, although to the last he retained a lively interest in all matters connected with engineering. He died on 11th May 1889, at the age of sixty, and was buried at Brompton Cemetery. He became a Member of this Institution in 1878.

George Wilson Stevenson was born at Derby on 10th April 1825. At the age of seventeen he became a pupil of Mr. Hawksley at Nottingham, and remained with him until the expiration of his articles. In 1847 he went to the United States, but returned to England within two years. He was soon appointed surveyor to the local board of Loughborough, from which he retired to enter into partnership with Mr. William Lee, an inspector under the Public Health Act. During this partnership he carried out several sewerage and water schemes. In 1856 he received the appointment of borough engineer to the corporation of Halifax, where he had almost at once to advise in reference to the purchase of the gas undertaking. The parliamentary contest was keen, and under severe cross-examination he at once proved himself an expert witness. The gas works, which were on the side of a steep hill, had to be entirely rebuilt; and great skill was shown in constructing the buildings upon the slope, so that the coal was brought in at the highest point, and the coke taken out at the lowest, with a minimum of handling. Throughout the ten years of his residence in Halifax

he was largely consulted in reference to gas and water undertakings, until he was compelled by increase of business to remove to London in 1866; since which date until within a year of his death he was in constant practice as a consulting engineer for gas, water, and sewerage works. In 1879 he published a book on "Precedents in Private Bill Legislation affecting Gas and Water Undertakings." He designed new gas works for Westbromwich, Scarborough, Colchester, Peterborough, and several other places; and altogether carried out either in their entirety or partially some sixty works for gas, water, or sewerage. His death took place on 23rd October 1889 at the age of sixty-four. He became a Member of this Institution in 1878.

William Stroudley was born at Oxford in 1833, and as a boy began work there in a paper mill, and afterwards entered a printing works. Thence he went to a fire-engine manufactory in Birmingham, where subsequently the foundation of his mechanical training was laid in the engine works of Mr. John Inshaw. He next entered the locomotive works of the Great Western Railway at Swindon, under Sir Daniel Gooch, then locomotive superintendent, and some time afterwards went to those of the Great Northern Railway at Peterborough. Here at twenty-two years of age he was foreman of fitters and running shed, under Mr. Charles Sacré. In 1861 at the age of twenty-eight he became principal foreman of the Edinburgh and Glasgow Railway locomotive works at Cowlairs, Glasgow. Here he built his first locomotive, which showed so many marked improvements that its appearance and early performances attracted general attention. In 1865 he was appointed locomotive superintendent of the Highland Railway at Inverness, where he designed the rolling stock for conducting the traffic under the very varying conditions of that line. Here he introduced the ramps known by his name, for getting an engine or carriage on the rails again after running off; and he also devised a snow-plough, which proved of great service in dealing with the winter traffic in the north. In 1870 he became locomotive superintendent of the London Brighton and South Coast Railway, and directed his first efforts to designing

and erecting the present locomotive works at Brighton and the running sheds, so as to be able not only to execute repairs, but also to build all the new engines and rolling stock required. He next proceeded to re-model the rolling stock, so as better to suit the traffic, by reducing the dead weight and increasing the carrying capacity. His first Brighton engine, the "Sussex" express, was followed by others embodying successively all the improvements he could devise; and at the Paris Exhibition in 1878 his "Terrier" tank engine, the "Brighton," was rewarded with the gold medal. His constant aim was so to design all the engines that their most important parts should be interchangeable, in order thereby not only to minimise labour, but also, by keeping these various parts always in stock, to obviate as far as possible the delays consequent upon unavoidable emergencies. The economical working of his engines both as regards coal consumption and cost of repairs was a marked feature, and proved of great benefit to the Brighton Railway, to which, owing to its distance from the producing districts, the question of cost of materials is a serious one. He also introduced the electric lighting arrangement in the Brighton Railway trains. The present fleet of steamers running between Newhaven and Dieppe was under his charge; and the latest additions to that fleet, notably the "Paris" and "Rouen" passenger ships, were built and engined from his designs. On 7th December 1889 he went to Paris, to take part in a series of trials between his latest engine, the "Edward Blount," which gained a gold medal at this year's Paris Exhibition, and the locomotives exhibited by some other English and French railways. In the course of these tests, while riding on his engine, he caught a chill, resulting in congestion of the lungs, from which he died in Paris on 20th December, at the age of fifty-six. He became a Member of this Institution in 1865.

Edward Walter Nealor Wood was born in London on 11th January 1856, being the only son of Mr. John Turtle Wood, the discoverer of the Temple of Diana at Ephesus. He was educated at Rossall and Finchley, and on leaving school was articled to Mr. William Baker, chief engineer of the London and North

Western Railway. During his pupilage he was for a time assistant to Mr. Louis Trench, resident engineer on the Newry and Greenore Railway; and subsequently had charge of the boring operations at Holyhead for the improvement of the old docks. On the completion of his pupilage in 1876 he was appointed assistant resident engineer on the Holyhead Harbour works, and afterwards on the Bangor and Bethesda Railway. Resigning this post in 1882, he was engaged in parliamentary and other work till 1884, when he was appointed resident engineer at Sholapur on the Great Indian Peninsula Railway under a three years' engagement. Returning to London in February 1888, in the following December he was appointed resident engineer on a railway being constructed near Huelva in the south of Spain, in connection with the Cabezas del Pasto Mine. There he died on 30th August 1889, in the thirty-fourth year of his age. He became a Graduate of this Institution in 1879.

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